A MANUAL

OF

EXAMINATION OF THE EYES.

A COURSE OF LECTURES DELIVERED AT THE "ÉCOLE PRATIQUE,"

BY

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TRANSLATOR'S NOTE.

THIS volume is not a mere translation of the French editions of Dr. Landolt's "Du Diagnostique des Maladies des Yeux," and "Manuel d'Ophthalmoscopie." The author has carefully revised these works, both in the original and in the translation for this edition; and so extensive have been these revisions, and so much new matter has been added, that it is, in many important particulars, a new book, and may be considered as representing as nearly as possible the status of the subject of which it treats at the time of its publication.

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LECTURE I.

INTRODUCTION.

GENTLEMEN :—I have hardly need to call your attention to the importance of the visual apparatus, when viewed from the stand-point of physiology. In this department of medical science it has always occupied a high place. You will more fully understand the extent and importance of the rôle it has played in our science when you call to mind that all the tissues of the body are represented in the eye and its accessories.

We ought, therefore, to find in these parts all the pathological alterations which are liable to occur in the various tissues of the body. And so we do find, not only a large number of general diseases, but many affections of other particular organs as well, reflected, in one way or another, in the eye.

The facility with which the visual organ can be examined enables us, frequently, to discern the manifestations of a morbid condition which would soon affect organs as yet intact, or which are only affected in a degree not at the time appreciable.

A few instances will make my meaning clearer :—

The anatomical richness, so to speak, of the visual apparatus is apparent at a glance.

We have, in the first place, the osseous tissue represented in the orbital walls. The connective tissue abounds in all its various forms; as cellular adipose tissue, forming a bed for the eye to rest in; as elastic tissue in the sclerotic and the sheaths of the optic nerve; again, in a homogeneous form in the membrane of Des-

cemet, the hyaloid membrane, the limiting membranes of the retina, the internal layer of the choroid, etc.; and yet further, in a form special to the eye it constitutes the cornea; nor should we forget that the vitreous humor is derived from the same blasto-dermic membrane.

The epithelium is neither less abundant nor less various in its forms. As the pavement variety it covers the anterior and posterior surfaces of the cornea and the iris, and the anterior capsule of the lens. It is scarcely necessary to mention cartilage, and muscular tissue of both the striated and non-striated variety.

Again, the nervous tissue is distributed to the eye in very great profusion. In classifying the organs of the body, we must assign the eye a first rank when we consider that, of the twelve cranial nerves, four are designed especially for it, and two others send branches to it. Six pairs of nerves, therefore, are required in its service: the optic (second pair), the motor oculi communis (third pair), the patheticus (fourth pair), the abducens (sixth pair), the trigeminus (fifth pair), and the facial (seventh pair), not counting the numerous filaments of the sympathetic.

Moreover, these nerves appear under all possible forms, as fibres, cells, ganglions and retinal tissue—that wonderful terminal expansion of the optic nerve.

How many different diseases can affect all these divers tissues I cannot now undertake to enumerate. It will suffice to call your attention to some of the general affections in which the eye may take part.

In *scrofula*, for example, you know that one of the most frequent external signs of the diathesis is a swelling of the lids, accompanied with redness and ulceration. But aside from this blepharitis—which has nothing of a special character, and resembles the other cutaneous manifestations of scrofula—we find, very frequently, in these subjects, other affections of the eyes, some of which are noticeable only on account of their frequent occurrence in the disease, while others have, beside this, a specific significance.

Among the first, we mention conjunctival and corneal phlyctenulæ, and among the latter interstitial keratitis. It is a matter of no small importance to know, for example, whether the ulcerations of the cornea which we find so frequently in children of a lymphatic temperament require, in addition to the treatment of their general condition, a carefully carried out local treatment, in lack of which irreparable damage is liable to be done. You have seen many of these cases of leucoma of the cornea in the clinics, which, when once they are formed, constitute an incurable defect.

Other affections attack, by preference, the fundus of the eye, where we can readily discern their presence. The *anemias*, whatever be their cause, are readily detected by the ophthalmoscope, in the decoloration of the optic papilla. While in Zürich, I saw a peculiar form of anemia which Professor Biermer has called *pernicious*, and which is characterized by the presence of multiple retinal hemorrhages.

It is to our learned teacher and friend, Professor Horner, who has done so much in applying the facts furnished by ophthalmology to general medicine, that we are indebted for the discovery of the ophthalmoscopic appearances of this affection.

Tuberculosis can, in certain cases, even when its presence cannot be demonstrated in the lungs, be diagnosed from the presence of tubercles in the choroid. I have often seen cases where the ordinary medical examination left the diagnosis uncertain between a meningitis and a typhoid fever, or other disease. When the ophthalmoscope had revealed to me tubercles in the choroid, there could be no longer a doubt that we had to do with a tubercular meningitis.

Even *rachitis*, which attacks only the osseous system, has its manifestation in the eye under the form of zonular cataract.

It is *syphilis*, however, which makes its appearance in the eye under the most various and most characteristic forms. We have it as iritis, gummata of the iris, retinitis syphilitica simplex, and neuro-retinitis accompanying gummy tumors of the encephalon.

We have also that form of keratitis called *parenchymatous*, which is so rebellious to treatment, as a product of the hereditary form of the disease.

While speaking of gummata of the iris it would be well to call your attention to another disease which produces tumors analogous in appearance, and yet of a nature entirely different. I allude to a special form of *leucœmia* in which we find, at the same time, an hypertrophy of the cervical ganglions and the parotid gland, keratitis punctata and yellow tumors of the iris. These tumors leave no trace of their existence after absorption, while the gummata destroy all the tissue of the iris in which they have their seat, with the exception of the posterior pigmented layer.

But of all the organs whose diseases are liable to affect the eye we must place the *brain* and *spinal cord* first.

You are aware that the diseases of the cerebral nervous system often produce in the organ of vision troubles which are either purely functional, or accompanied with lesions objectively appreciable.

Among the first class we cite, as the most important, paralysis of the ocular muscles, either extrinsic or intrinsic, as the sphincter of the iris and muscle of accommodation.

We frequently find strabismus, irregularity of the pupil and other symptoms accompanying a number of affections of the brain and its meninges. The same may be said of those perturbations which the peripheric or central portions of the retina present, as regards acuteness of vision and the perception of colors. Restriction of the field of vision, scotomata, and hemiopia in particular, are all symptoms which have great diagnostic value, in so far as they often assist us in specifying the lesion present in the brain, or in localizing its seat.

Encephalic affections are also liable, as we have said, to bring about changes in the fundus of the eye that can be examined by the ophthalmoscope.

The inflammation of a meningitis, for example, may be propa-

gated directly along the optic nerve to the retina, and sometimes even to the vitreous humor.

Tumors, which increase the intra-cranial pressure and that of the sub-arachnoidal space, cause, through the inter-vaginal space of the optic nerve, a stasis of the veins of the retina, serous and hemorrhagic exudations in that membrane, engorgement of the optic nerve, with strangulation of the papilla with its consequences (choked disc).

In a less degree the increase of the intra-cranial pressure may manifest itself by a hyperæmia of the papilla, so that the papilla becomes, in a measure, a page on which we may read the variations which the intra-cranial pressure undergoes.

There are, furthermore, certain diseases of the *heart* which are manifested through a pulsation of the central vessels of the retina. *Bright's disease* has often been recognized through a retinitis of a special form when the existence of albuminuria had not yet been demonstrated.

Then, too, there are *parasites* to be found in the organ of vision, whose presence, when revealed by the ophthalmoscope, establishes often the nature of an affection previously undetermined, and of which they are the direct cause.

It would be easy to multiply examples. These are diabetic cataract and retinitis, the dyschromatopsia of jaundice, etc.; but the instances we have cited are sufficient to show the importance of a knowledge of the elements of ophthalmology, particularly that portion of it which treats of the examination of the eyes, and the service it may render even to those among you who will leave to specialists the treatment of ocular affections.

We think we are warranted in saying that as external objects are pictured upon the interior of the eye, the eye, in its turn, becomes a mirror, as it were, from which is reflected what is going on in the interior of the body.

But if ophthalmology has become, within the last twenty-five years, an exact science, it is not alone on account of the interest

it has universally excited, but more particularly because we have been enabled to subject the eye to the most thorough and accurate examination as regards its tissues and functions.

I remember that, at the beginning of my medical studies, one of those impatient spirits of young Russia said to me, "We must not deceive ourselves. Medicine does not merit the name of science, it is pure empiricism."

These words made a deep impression upon me, because they had a tendency to dampen the enthusiasm with which my new studies had inspired me.

Afterward, when I came to frequent the clinics, I will not say that I fully realized the truth of the remark of my friend, but I must say that the manner in which medicine was yet studied did not leave it entirely without a foundation in fact. And in glancing back over the history of our art we see that purely empirical medicine is not yet so antiquated.

What is it, then, that has given a soul to the dead body of empiricism? To what shall we attribute the impulse which has ended in the creation of scientific medicine? To this, that medicine has been willing to profit by the teachings of chemistry and physics. It is chemical analysis, histological analysis, percussion, auscultation, thermometry, the use of such instruments as the spirometer, the sphygmograph and the microscope, and the application to clinical investigation of the various methods and instruments of chemical and physical science that, placing medical study on a scientific basis, has remodeled it as an art.

But you may ask, what is the essential advantage of all these means of examination? It is this, that we are thus enabled to express exactly, in figures and by curves and diagrams, the forms and functions of the various organs of the body.

As a proof of this tendency of modern medical thought, I will instance the fact that it was a physician who established the law of the convertibility of forces and the indestructibility of matter—the two principles at the bottom of all actual science.

We can to-day not only estimate with great exactness the value of an aliment, the heat and work which it can furnish, but we know how to utilize these facts according to the need of the organism, just as we determine the quantity of combustible material required by a machine to furnish a given amount of force.

The examination of the urine has become, thanks to chemical analysis, one of the most scientific means of diagnosis.

We can now determine exactly the position, relations and dimensions of many organs of the body about which we had, in former years, but the most indistinct ideas.

We now determine the variations in the temperature of the body, not in a general way, as formerly, but up to the fraction of a degree. The characters of the pulse are no longer judged by the sense of touch, more or less delicate, of each individual practitioner, but they are recorded in their most minute details.

These methods, and many others that could be mentioned, have given medicine an honorable and legitimate position among the sciences, because they substitute for simple approximations or guesses the most certain methods of examination, and for the variability of individual sensations the inflexibility of figures.

Now, no other organ in the body is so well adapted for the application of the exact sciences as the eye. This is why the study of the function of the eye, though begun only within a very recent period, has become the most highly developed department of physiology. And for the same reason the treatment of eye diseases, based as it usually is upon a certain diagnosis, aided by the accessible position of the organ, is the most efficacious in the whole range of therapeutics.

It is the diagnostic part of ophthalmology with which we shall occupy ourselves in this course of lectures, that is, we shall study the means and methods of examining the forms, functions and diseases of the apparatus of vision.

The science of the examination of the eye in a healthy and diseased condition—the *metrology* of the eye, as we call it—is of

very recent date. It is not more than thirty years since we were content to establish the fact whether the patient could see or not.

In the latter event two grand classes were distinguished—amaurosis and amblyopia—which were differentiated thus: in amblyopia the patient saw nothing, but the physician saw something; in amaurosis neither the physician nor the patient saw anything.

Under the name amblyopia were grouped all those visual troubles produced by lesions appreciable by the naked eye, such as leucomata of the cornea, occlusion of the pupil, etc. On the other hand, all those troubles which had their seat in the interior of the eye, such as retinitis, choroiditis, atrophy of the optic nerve, etc., were classed under the head of amaurosis.

The opinions respecting refraction and accommodation that were held in those days seem almost incredible to us now. The action of the dioptric media of the eye was for physicists themselves the subject of most curious conjecture, while the physician was greatly perplexed by questions which to us are the most simple, such, for instance, as relate to the use of spectacles. Who can tell how many of the incurable cases of myopia which we see even now are due to the improper use of these most useful instruments?

The ideas prevalent regarding the movements of the eyes were not more advanced. An evidence of which is the lamentable results of so many of the old operations for strabismus. How many of the afflicted are we now able to relieve, who would formerly, for the want of proper means of diagnosis, have been abandoned to their fate?

It is to an Englishman, Thomas Young, a man of exceptional learning and intelligence, that we are indebted for the first important work in the line of examination of the organ of vision. But his views were so far in advance of his time (he lived at the end of the last and the beginning of the present century) that they found neither comprehension nor acceptance at the hands of his contemporaries.

It was reserved for Helmholtz to rediscover the works of this

English *savant.* But it was this great genius himself who, by his own labors, really founded scientific ophthalmology, the department of metrology in particular. With his ophthalmometer he laid the foundation of physiological optics, with his ophthalmoscope that of medical optics.

Availing himself of these newly-discovered facts, Donders, the renowned physiologist of Utrecht, was enabled to expose, with a clearness and precision without parallel, the laws governing refraction and accommodation, and to apply them to the demands of practice. It is only since the publication of his classical work on the "Anomalies of Refraction and Accommodation" that we have had any clear ideas respecting myopia, hypermetropia, astigmatism and presbyopia, and have been able to correct, in a rational manner, the different forms of ametropia, and thus give to a large class of patients a means by which they could pursue their work with satisfaction and comfort. It would be a gross injustice, however, to pass over the names of those who have extended the work begun by Donders — Javal, MacGillavry, Giraud-Teulon, Knapp, Nagel, Mauthner, Green, Loring, Couper, Dyer, Thomson, and many others.

During this time the ophthalmoscope, introduced into practice specially by the school of Gräfe and by Jäger, underwent a series of modifications, all tending to enhance its value. Donders applied it to the measurement of objects at the fundus of the eye. Giraud-Teulon gave relief to the ophthalmoscopic image by adapting it to binocular vision, while Sichel and others rendered an examination possible by several persons at the same time. A number of other names belong to successive modifications and applications of the instrument.

I have myself treated of the enlargement of the ophthalmoscopic image, and of the correct appreciation of the size of the objects observed.

Snellen furnished, in his test-types, the first scientific method for the determination of the acuteness of vision. He has also

enriched metrology with numerous instruments for measuring exophthalmus, strabismus, intra-ocular tension, etc. His *metroscope* has had its use extended beyond the limits of ophthalmology into the domain of geometry.

Our own *diplometer*, which is most useful in measuring the different parts of the eye, such as the size of the pupil, the reflections from the different refracting surfaces, etc., irrespective of the movements of the globe, has also found applications outside of ophthalmological science.

Since the centre of rotation of the eye has been determined by Donders, J. J. Müller and others, the ocular movements have been worked out in a very exact manner by Hering, von Gräfe, Javal and others.

Aubert and Foerster have brought forward methods for the more exact determination of the perception of light and the limits of the field of vision. After some Russian physicians, Reich and Uschakoff, I have myself, by means of my *perimeter*, examined into the functions of the peripheric portion of the retina, the results of which have been applied with great advantage in the practice of general medicine.

Aubert has also contributed largely to our knowledge of the physiology of the retina, and more recently Hering has advanced a most ingenious theory on the perception of light, and of colors in particular.

The examination of the perception of colors has added much to ocular symptomatology, thanks to the researches of Dalton, Clerk-Maxwell, Leber, Stilling and others. You will see at some of our future meetings what means we have for examining this delicate function, and also the service the knowledge thus gained has rendered to general medicine.

Thus, a small but valiant army of ophthalmologists labor, without ceasing, to increase and perfect the means of examining the visual apparatus, in order to be able to treat most successfully its diseases and those of the organism in general.

We shall see further on that a new step has been taken which had its origin in ophthalmology, but whose advantages extend throughout the entire field of optics. I allude to the recent introduction of the metric system into ophthalmology.

The temptation is very great to treat the subject we have chosen in a strictly scientific manner, for in this, in fact, consists its great charm and value. But there is another manner of considering it which is at the same time attractive, and which will conform more strictly to the objects you have in view. We shall therefore leave to physiologists the task of working out those problems which are purely scientific, and only occupy ourselves with those which are indispensable to our daily practice.

Those who desire to enter more profoundly into the subject will find the questions fully treated of in the chapter on *Metrology* which we have published in conjunction with Snellen (*Handbuch der gesammt. Augenheilk., B. III*), and even more extended in the work we are at present publishing in connection with Wecker (*Traité Complet d'Ophthalmologie, Paris*, 1878).

We divide the subjects we shall treat of in this course of lectures as follows: 1st. The objective general inspection of the eye; 2d. Examination of the lids, conjunctiva, lachrymal passages, and all the other portions of the organ accessible to the naked eye; 3d. Determination of the distance between the two eyes, their height and protrusion; 4th. The movements of the eyes, particularly in their relation to strabismus; 5th. Intra-ocular tension; 6th. Acuteness of vision; 7th. Refraction and accommodation; 8th. Perception of colors; 9th. Limits of the visual field and indirect vision; 10th. Ophthalmoscopy, including the examination of the dioptric media by means of the oblique light.

Of none of these things should a physician of to-day be in ignorance. You should not leave them to the study of the specialists if you would bring to your work as general practitioners all the resources of modern diagnosis.

LECTURE II.

EXAMINATION OF THE EXTERIOR OF THE EYE.

GENTLEMEN :—In the examination of the eyes, as in the examination of any other portion of the body, we should follow some systematic method. This is absolutely necessary if we would overlook nothing and attain our ends with certainty.

We shall divide our examinations into *objective* and *subjective*, the first having for its object to make us acquainted with the eye in a state of functional inactivity, the second to determine the condition of the function of vision.

The *objective* examination should begin with a general inspection of the patient at a distance, in which we note all that we are able to observe as to his general appearance, and, in particular, the appearance of his eyes, as, for example, their position, etc.

Afterward, we examine all the parts of the visual apparatus which are accessible to the naked eye: the lids, lachrymal passages, conjunctiva, the form and size of the globe, the cornea, sclerotic, iris, crystalline lens, and anterior portion of the vitreous humor. The examination is completed by the determination of the ocular tension.

In the *subjective* examination, the various functions of the eye are passed in review, such as movements, refraction and accommodation, acuteness of vision, perception of colors, limits of the field of vision, the periphery of the retina, etc.

Finally, the examination with the ophthalmoscope and the oblique light will show us the condition of the interior of the eye and the dioptric media, and also give us definite ideas regarding the refraction.

Ophthalmoscopy will form a part of the objective examination; but this always dazzles the eye to a greater or less degree, and renders the functional examination afterward somewhat less satisfactory. Moreover, the ophthalmoscopic examination requires a dark room, and it is better to make, at first, all those examinations that are possible by daylight. Moreover, the facts gained by subjective examination are very useful in interpreting the ophthalmoscopic appearances. These are sufficient reasons for reserving the ophthalmoscope for the end of our examination.

First, then, of the *objective examination* of the patient.

The first thing to which we should direct our attention is the general condition of the individual under examination. The eye is not a part of the body separate and distinct from the other parts, any more than ophthalmology is a branch isolated from the other divisions of medical science.

When you have to do with an affection of the eye it is, therefore, advisable not to begin with an examination of that organ, but to first take a glance at the general aspect of the patient.

Such a rapid general inspection will frequently furnish us with a clue to an ocular affection, the cause or origin of which would otherwise have escaped our notice. It will give us greater security in the diagnosis, more assurance in the presence of the patient, and more certainty in the direction of our treatment.

For example, the *form of the cranium* is often in direct relation to the conformation of the eye. Now, the form of the eye is that which influences most largely its refractive condition; you can therefore judge, with a greater or less degree of certainty, of the state of the refraction by the shape of the head.

It is known that hypermetropia depends, in the majority of cases, on a want of development of the eye in length, while myopia, on the contrary, is due to an elongation of the eye in its longitudinal axis. In other words, long eyes are generally myopic, while short eyes are, on the other hand, mostly hypermetropic.

This difference is frequently pronounced in the appearance of

the features of the patient. A flat or "dish" face, especially if the flatness affects the region of the zygomatic arches, is nearly always an infallible indication of hypermetropia.

Myopia is indicated by characters of the opposite kind.

In Switzerland, where myopia, hereditary or acquired, is very frequent, I have found two types of conformation of the cranium in connection with this state of refraction :—

In the first, the cranium is elongated in its antero-posterior diameter; the face is narrow from side to side, while the nose and the middle portion run prominently forward, the eyes protrude almost entirely out of their sockets, and their anterior portions stand almost even with the bridge of the nose. In consequence of this, the palpebral aperture is excessively large. I have seen, for instance, in a myopic young woman, the movements of the eyes much restricted by the palpebral aperture, so great was the projection of the globe. She had already had done for her the operation of blepharo-phimosis. While in this first form the forehead is retreating, in the myopes of the second category it is straight and broad. The tuberosities are strongly developed, the nose flat. The eyes are sunken in a deep orbital cavity, protected by prominent brows.

A *lack of symmetry in the face*, one half being flatter than the other, would lead us to suspect *anisometropia*, a condition in which one eye is myopic and the other hypermetropic.

All forms of *asymmetry of the cranium* can cause *astigmatism*, that irregularity of the dioptric apparatus in which the meridians of the cornea of the same eye have different curvatures.

For example, we find, sometimes, faces in which the median line instead of running vertically makes a kind of lateral curve; the line which joins the middle of the forehead with that of the chin is thrown to one side, and no longer coincides with the vertical corresponding to the bridge of the nose. This form of asymmetry is especially manifested by a lateral curvature of the nose.

This is the result of one side of the face being more developed

than the other. The frontal tuberosities, the zygomatic arches, the maxillæ, are much more prominent on one side than on the other.

Individuals with such a conformation of features are, nearly without exception, astigmatic, and very frequently anisometropic; the refraction is then the stronger on the side which is the more fully developed, this eye generally being myopic, or at least emmetropic, while the other eye is, as a rule, hypermetropic.

There is another circumstance which is also worthy of attention: certain individuals have—it may be congenitally, or in consequence of an accident or disease, such as syphilis—a sinking of the root of the nose. This predisposes to catarrh of the lachrymal passages. Now, in these persons the nasal duct is usually very narrow and irregular in its course. It is well to bear this fact in mind, because the sound, which is the basis of all treatment of catarrh of the lachrymal sac, is inserted, on account of this irregularity, with great difficulty, and a very serious obstacle is thus thrown in the way of the management of these cases. This general appearance of the features of the patient will, therefore, furnish us with very important indications as to the direction in which the sound shall be introduced. If, for example, the osseous parts corresponding to the lachrymal sac take part in the depression at the root of the nose, or if, aside from any pathological condition, the superior portion of the orbit is very prominent, you should give the sound a strong curve, and in inserting it press not only in the vertical direction, but make the free extremity sweep toward the upper edge of the orbit, and finally direct the lower extremity toward the front.

I mention this point incidentally here because you will find it of great utility in practice.

When the patient speaks to you do not neglect to take a glance at the teeth. You know that *Hutchinson's teeth*, wedge-shaped, with notched edges, indicate, nearly without an exception, the existence of hereditary syphilis. On the other hand, indented

teeth, striated horizontally, are suggestive of rachitis, which is frequently accompanied by zonular cataract.

If it is important to observe the formation of the cranium in our patients, the *examination of the skin* is not less useful.

Certain cutaneous diseases, pityriasis and eczema, for example, can affect the lids as well as other portions of the body. We treat them in the same way, but more carefully and with greater solicitude, because of the pernicious effects which they are liable to produce in such a delicate part; the swelling of the lids is of itself sufficient to interfere with vision, but consider the serious troubles which a faulty direction of the lashes, due to a long-continued inflammation of the edges of the lids, can bring about.

Other affections of the skin, not directly implicating the lids, furnish no less important indications for a diagnosis of ocular troubles.

If you find, for instance, on a patient, traces of a *syphilitic eruption*, and at the same time diagnose an iritis, you know positively that the iritis is of a specific character, and demands, aside from the ordinary local treatment (atropine and exclusion of light) an appropriate general treatment.

Neither should you forget that there is a connection, frequently, between diseases of the choroid and those of the skin, as has been pointed out by Horner.

An eruption, or cicatrices of an *herpetic* nature, characterized by their unilateral position, and corresponding to the distribution of a nerve, will frequently lead us to the recognition of an herpetic keratitis, which is often confounded with simple phlyctenular keratitis. These two affections of great similarity in appearance are readily distinguished the one from the other by this, that the former, aside from its limited distribution, is accompanied by anæsthesia of the cornea, and is exceedingly rebellious to treatment; the second, on the contrary, recedes rapidly under the insufflation of calomel. Moreover, there is frequently found in

the first of these affections a diminution of the intra-ocular tension, which is absent in the second.

You will be able to recognize, by the peculiar hue of the skin, that form of chronic iritis which frequently accompanies leucæmia, and the special danger of which is the production of punctated deposits on the membrane of Descemet and yellowish tumors on the iris. In this connection you will remember what I said about this form of disease in the first lecture.

From these examples you will see how important it is to take a general survey of the patient, and how often it gives us a clue to diseases affecting the eyes. Whoever neglects to avail himself of these helps voluntarily deprives himself of one of the elements of an accurate diagnosis.

Afterward you will proceed to a special examination of the eyes.

And here, again, you should begin with a general inspection. You should first look at the two eyes at the same time, comparing the one with the other. Many grave lesions are liable to escape the notice of those who neglect this comparison and limit their examination to the eye which appears affected, or only look at one at a time.

Sometimes a slight divergence of one eye, or an inequality in the dilatation of the two pupils, is sufficient to lead us into the way of a diagnosis of an encephalic affection.

Tumors of the orbit or brain produce frequently a lateral displacement, or an exophthalmus not sufficiently pronounced to be detected except by a comparative examination of the two eyes.

A *difference in the size of the palpebral opening* could not easily escape your notice; but in all these cases take care to determine whether you have to do with a ptosis in one of the eyes or an excess of separation of the lids in the other. If it be a ptosis on one side the upper lid of that side cannot be elevated to its fullest extent, while that of the other eye will enjoy the full measure of its movements; in the case of extreme separation of the lids the eye will not be able to close itself completely, but,

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the cornea concealing itself involuntarily under the upper lid, is directed upward.

This phenomenon is most marked in the cases where the upper lid is retracted by cicatricial bands. We can otherwise make it manifest only by holding the upper lid up for some time; then, when the orbicularis muscle contracts we see the eye roll itself upward in search of the lid.

Never neglect to make an examination of the *lachrymal sac.* For this purpose you must press lightly on it from below upward; you will then see, if there be catarrh of the sac, a liquid, more or less purulent, issue from the lachrymal punctum. It frequently happens that ulcers of the cornea persist for an indefinite length of time, from no other cause than the long-continued contact of this irritating matter, of the presence of which we had not before a suspicion. This affection of the lachrymal passages has even a greater importance when we have under consideration an operation on the eye. It influences very materially the healing process.

Next comes the examination of *the edges of the lids.* I shall not say anything further in regard to blepharitis ciliaris, in addition to what I have already said. But I would call your attention to the position of the lashes, which it is of the greatest importance to examine. How many patients do we see affected with iritis, keratitis, and other still more serious inflammations, and for which they have undergone all sorts of treatment, where a displaced eyelash has been the whole cause of the irritation. Never, therefore, neglect this part of the examination.

We pass on now to the *conjunctiva.* We are too often satisfied to simply give a glance at the conjunctiva which covers the globe or the inner surface of the lower lid. This is not sufficient, because the most important part to examine is the conjunctiva of the upper lid, and especially the upper cul-de-sac. It is there, and frequently nowhere else, that we find granulations which keep up a persistent conjunctivitis, which will be rebellious to treatment

so long as we do not discover the source of the trouble and attack the granulations themselves.

The inferior cul-de-sac, or retro-tarsal fold, is quite accessible; we have only to apply the tip of the finger to the edge of the lid, and then cause the patient to look upward while we pull the finger downward. This everts the lid and brings out the cul-de-sac.

For the upper lid we employ a similar proceeding, but there is greater difficulty in everting it, on account of the breadth and resistance of the tarsal cartilage. The patient should look downward while you seize gently, with the thumb and index finger, the edge of the lid; with the other hand you apply some resisting body, as the point of a pencil, or even the end of the finger above the cartilage, and make a rotating movement with the other hand around this body as a centre. The internal surface of the lid being brought to view in this manner, you can expose it still further by drawing the edge yet higher and pressing it against the edge of the orbit.

It is astonishing what we sometimes find hidden away under the upper lid. It is not only the seat, by preference, of granulations of the conjunctiva, but also of foreign bodies of all kinds. A grain of sand, a bit of coal, whenever they fly into the eye, nearly always seek refuge here, and it frequently happens that these small bodies, remaining concealed in the retro-tarsal fold for months and even years, occasion an obstinate and painful conjunctivitis, which leads frequently to papillary hypertrophy of the mucous tissue. Would you believe that I have found in three different cases "eye-stones" which the patients had introduced under the upper lids in order to drive out a grain of sand?* And what is still more astonishing than the remedy, is that these gentlemen lived quietly for years with a purulent conjunctivitis which almost completely disabled them from work, and which was due entirely to the bodies in question, encased in the hypertrophied

* It is the custom in some portions of the United States to introduce, for this purpose, a flax seed into the eye.—*Tr.*

papillæ. I have scarcely need to say that, in all these cases, a removal of the cause sufficed to effect a cure.

We now proceed to an examination of the *eyes proper*, and we should first observe their general aspect.

We should direct our attention successively to the *distance between the two eyes*, and to the *difference in the height of the eyes*; afterward to the degree of their *prominence—exophthalmus*, and finally to the *direction of the visual lines*.

The *distance between the two eyes* does not offer, in general, differences appreciable at first sight, and yet it is a question worthy of our attention.

As an evidence of this I need only call attention to the part which this distance plays in the act of convergence. You know that in reading, near work, and the close examination of objects, we must make a convergence of the eyes. Now, you will easily understand that in fixing an object placed at a given distance, the more widely the eyes are separated the greater must be the effort at convergence. Thus, for different eyes fixing at the same distance, the angle of convergence can vary more than ten degrees. You can readily conceive that this increase of work, even if it amount to only a few degrees, may end in an exhaustion of the internal recti muscles, which, during the whole of life, have to produce this convergence.

For my part, I am thoroughly convinced that the insufficiency of the internal recti, which is such a frequent cause of the asthenopia of myopes, is due in many cases to an excess of the distance between the eyes.

This important question has hitherto been almost entirely overlooked, with the exception of some researches made by Mannhardt and Pflüger. It is a question which deserves a thorough study, for we will find in it many new and instructive facts, and an explanation of some other facts already known, but whose significance has been heretofore falsely interpreted.

The principal difficulty in the study of the subject consists in

the absence of an exact method for measuring the distance between the eyes. It is, indeed, almost a matter of impossibility to measure this distance with a graduated rule, because, what point shall we take to measure from? The centre of the pupil? In the first place, the pupil is not in the centre of the anterior part of the globe, but a little to the inner side. And further, the centre of the pupil can only be determined approximately, which would give chances of error.

Should we take, as proposed by Horner, the edges of the cornea, the external of one side, the internal of the other? This method is no more exact than the preceding, because the edges of the cornea are frequently very unequal, and it is difficult to find the corresponding points on the same horizontal diameter.

These methods have, moreover, a very serious defect in this, that we cannot apply the graduated rule to the points the distance between which we desire to measure, the bridge of the nose opposing a very considerable obstacle.

In the last place, and this is an essential point, you should not forget that the distance which separates the corresponding points of the two eyes (centres of the pupils or edges of the cornea) only represents the distance between the eyes in a single condition, and that is when the eyes are directed in lines parallel to each other. If we measure this distance in a condition of convergence it is too small; if in a state of divergence it is too great.

Now, it is impossible for any one who has not specially practiced to that end, to give his eyes a direction absolutely parallel. There always remains a greater or less degree of convergence, and the surgeon has no means of judging whether the eyes of his patient are parallel or not.

And the still further disadvantage of this method is that it cannot be applied to the eyes of those affected with strabismus, the very eyes in which it is most important to know the interocular distance. It is evident that these individuals never bring their eyes to a state of parallelism.

The employment of the graduated rule is justifiable only in those cases where we desire a simple approximative measurement, as when we want to determine the distance which should separate the glasses of spectacles.

And even for these cases I would advise you to employ my *double rule,* of which we shall speak further on, or to proceed in the following manner:—

Place yourself in front of the patient, and cause him to fix an object in the distance. This will give his eyes an essentially parallel direction.

Then apply your graduated rule over the nose of the patient, and closing the right eye, sight, with the left eye over the point marked zero on the rule, to the centre of the pupil of the right eye of the patient. Afterward, closing your left eye and opening your right, you read off on the rule the point which is opposite the centre of the pupil of the patient's left eye. It is, of course, understood that you should, during the examination, make no movement of your own head.

In this manner you avoid almost entirely any parallax; but the method is not applicable to strabismic eyes, and moreover, I do not propose it to you as perfectly exact.

Finally, it is not the inter-pupillary distance with which we are concerned. What is it we really want? To properly appreciate the work of the internal and external recti muscles in the different degrees of convergence. We should, therefore, address ourselves to the only parts of the eyes which remain fixed during their movements. These fixed points are the centres of rotation.

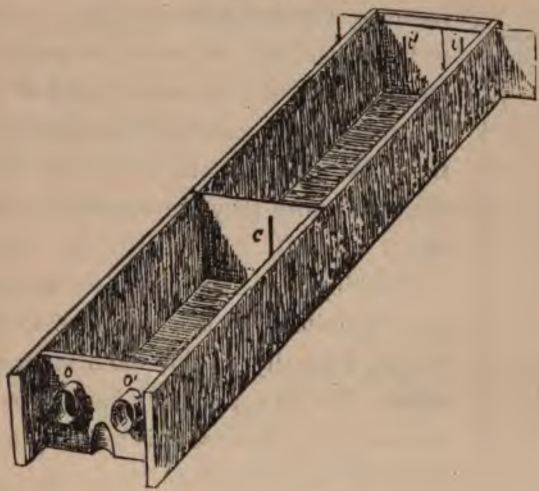
For measuring the distance which separates the centres of rotation I have devised the following apparatus:—

It is a box (Fig. 1) having the form of a rectangle, of sufficient length, one end of which has two holes (c c') for the eyes and a depression for receiving the nose.

Each of the two openings is provided with a short tube in which to place the eye, and they can be separately closed by a movable slide from the inside.

A vertical plate divides the box into two parts; it is situated exactly in the middle of the distance separating the further extremity of the box and the line uniting the centres of rotation of the eyes.

FIG. 1.



The further extremity of the box is closed by two plates, which can be moved separately in a lateral direction. In each of these is a vertical slit (i' and i). A similar slit (c) is made in the middle of the central diaphragm. A cover encloses the whole.

To measure the distance between the two eyes we apply them to the anterior extremity of the box, each one looking through its appropriate opening. By means of the slide on the interior, one of the openings, for example, the one corresponding to the left eye, is closed, and the right eye alone looks into the box. This eye can see nothing so long as the slit in the middle and the slit on the left at the other end do not correspond with the visual axis of that eye. We can bring this about, however, by a suitable movement of the left movable plate at the further end of the box.

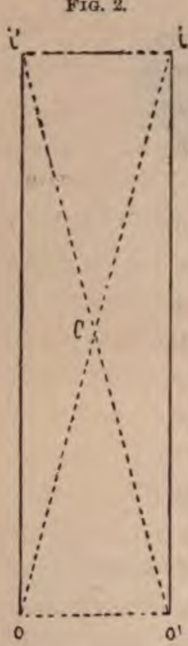
We proceed in a similar manner with the other eye.

You can easily understand that the distance (i' i) between the

two movable slits so placed will represent the distance (o o') which separates the two eyes, since the distances are bases of two equal triangles (Fig. 2).

It is easy, however, by using the same principles, to arrive at the same result in another manner. Take, for instance, a rectangular plate with a needle fixed in its centre, and at one of its extremities two movable needles; the eyes placed at the other extremity sight, one after the other, by the central fixed needle, at the needles beyond, moving the latter until they are covered by the central one.

FIG. 2.



Thinking that it is easier for our patients to mark definitely the moment when they perceive a light, I usually employ the first form of apparatus. To this apparatus I have given the name *chiasmometer*, because it is based upon the crossing of the visual lines.

To obtain greater exactness in this method we can place in the central slit a fine thread or hair, which should appear exactly in the centre of the illuminated space when the central slit coincides with one of the slits at the further end.

The great advantage of this method is that it requires neither a parallelism of the two eyes nor a simultaneous fixing of the same point. This enables it to be applied even to strabismic eyes, and to cases where there is an insufficiency of the muscles.

We will now consider the methods for measuring the displacements which the eye may suffer, either *in height* or in an *antero-posterior* direction. These displacements are due most frequently to tumors growing in the orbital cavity; there are also encephalic tumors which may give rise to them. It is these displacements of the eye which furnish the most precise indications as to the growth or decrease of the tumor. It is, therefore, not sufficient to

demonstrate the existence of a displacement, but it is necessary to measure its degree, in order to fully appreciate the changes it may undergo.

It is generally easy to recognize differences in the height of the two eyes. It usually suffices to let the patient hold the head perfectly erect, when, in moving the eyes, the affected one will appear to be restricted in its movements in the direction opposite to that of the displacement; a tumor on the lower wall of the orbit will restrict the downward movements and displace the eye upward.

In order to approximate the degree of displacement we hold on a level with the pupil of the unaffected eye a rule perfectly horizontal, and estimate the number of millimeters which the pupil of the other eye is displaced above or below this level; if we want to be more accurate we hold another rule perpendicular to the first, on which we measure the extent of displacement precisely.

In those cases where the vertical displacement is so slight as to escape our notice there is a subjective symptom which will not fail to furnish evidence of its existence, and that is *diplopia.*

Diplopia is called forth whenever there exists the least difference in the height of the two eyes, and it is so much the more troublesome because the double images can be united, if at all, only with the greatest difficulty. In the horizontal direction a strong contraction of one of the recti, or a slight rotation of the head, suffices to reëstablish single vision; here it is not so, and it is frequently the diplopia alone which brings the patient to the surgeon.

In such a case it should be determined whether the diplopia is due to a total displacement of the eye, or whether it is a consequence of an *incomplete* muscular paralysis. I say *incomplete*, because the deviation which follows a complete paralysis will never be confounded with a total displacement, and *vice versa.*

Let us suppose, for example, that the left eye of a patient

[illegible] than the right. The patient sees double, the [illegible] being lower than that of the right. Is there [illegible] of the left eye, or an incomplete paralysis of [illegible] in consequence of which the anterior portion [illegible] upward?

[illegible] displacement of the globe, the diplopia will persist [illegible] the point of fixation; it will diminish, on [illegible] more and more, and finally cease, at a certain elevation, [illegible] paralysis of the inferior rectus.

[illegible] moreover, the image of the affected eye will [illegible] below the other but drawn toward the other eye and [illegible] upper part toward the left side, which would not be [illegible] total displacement of the globe.

[illegible] in future lectures that complex symptoms, analogous [illegible] accompany other muscular paralyses; these symptoms [illegible] in displacements of the globe.

[illegible] add that a tumor, an exostosis, for instance, need [illegible] the eye, in one direction only. In the majority of [illegible] shall have, independently of the displacement, vertical [illegible] also a protrusion of the eye of a greater or less degree.

[illegible] of the eye is a symptom yet more important [illegible] other forms of displacement.

[illegible] the first place, a more constant phenomenon, because [illegible] portion of the orbital cavity is the only direction in [illegible] the globe can recede before the increase of volume of the [illegible] surrounding it.

We find, therefore, protrusion as a principal symptom in abscess, [illegible], hyperostoses, tumors, cysticerci of the orbit, etc., and we find it especially in *Basedow's disease* (exophthalmic goitre).

The protrusion of the eye, moreover, is of prime interest, on account of the pernicious effects which it entails upon the cornea and other portions of the eye.

In Basedow's disease, for example, the exophthalmus frequently attains to such a degree that the lids no longer suffice to cover the

cornea; this latter, then, begins to ulcerate, to dry up, desquamate, and the trouble ends frequently in its total destruction and a complete loss of vision.

We can measure the protrusion approximately, by taking, as a point of departure, the external edge of the orbit, and determining the distance which the cornea of each eye extends beyond it. For this purpose we employ a graduated rule, which is applied horizontally against the external wall of the orbit, and observe on the rule the point corresponding to the apex of the cornea.

It is evident that this method is not very exact, because we are not always certain that we sight the cornea at a right angle. We can avoid this error by using my *double rule.*

This small instrument is composed of two rules divided in millimeters, fixed parallel to each other at a distance of about one centimeter, and in such a manner that the perpendicular lines marking the divisions of the rules shall correspond exactly. We apply the zero point of this double rule against the edge of the orbit and sight the apex of the cornea across it. If the two corresponding divisions on each rule and the apex of the cornea are in a line, we are certain that we have sighted at a right angle to a line perpendicular to the cornea.

This method suffices in the majority of cases, and as it measures easily with the exactness of one half a millimeter, can replace all such instruments as protrusiometers, exophthalmometers, etc., which have been invented to measure exophthalmus, and which I do not think it necessary to describe.

There is a condition, however, where this method cannot be applied, viz., where the orbit has taken part in the process which produces the exophthalmus. The orbit cannot then be taken as a point of departure for measurement, and can no longer be compared with that of the other side. But there is one point that yet remains the same, and that is the bridge of the nose.

We can therefore find the distance the bridge of the nose is in advance of the apex of the cornea on each side. This plan of

measurement is, however, not so simple as the preceding, because we can apply the graduated rule neither on the bridge of the nose nor on the cornea; it is therefore necessary to sight the two points at a distance.

The amount of protrusion gives us no knowledge of the nature of the tumor. We endeavor to obtain some idea of this from the resistance offered by the globe to the finger in pressing it into the orbit.

For this purpose, we apply the hands to the temples, while with the thumbs we make light, but increasing, pressure on the two eyes. In this manner we can easily ascertain if the affected eye gives way under the pressure as much as the other, or if it retains its position in the orbit, or if it eludes the pressure, and in what direction.

Exostoses, tumors of very great consistency, it is evident, do not allow of much movement on the part of the globe, while serous exudations into the orbital tissue, and even abscesses, are quite compressible.

If the eye gives way always in the same direction under the pressure of the finger, we can be pretty certain that there is a tumor of considerable consistency on the orbital walls in the direction opposite to that in which the eye gives way.

I will not describe here the instrument of Snellen, by which we measure at the same time the protrusion and reducibility of the eye. I would refer you for a description of the instrument and the manner of using it to our work on *Metrology.** The sensibility of an educated finger is generally sufficient in practice.

* **Handbuch der Gesammt. Augenheilk., B. iii, and Wecker et Landolt Traité Complet d'Ophthalmologie, Tom. i.**

LECTURE III.

MOVEMENTS OF THE EYES.

Gentlemen:—Having now determined the *position* of the eyes, we turn our attention, next, to their *direction*.

Unfortunately, we have not time to study thoroughly the physiology of the movements of the eyes. Some knowledge of this subject is, however, essential to a proper understanding of the pathological derangements to which they are liable.

You know that the eye is moved by six voluntary muscles.

These muscles, taking their origin mostly from a tendinous ring around the optic foramen (Fig. 3), pass over to the globe of the eye, some directly, others after reflexion, and become attached to the sclerotic, each by a broad, flat tendon.

Four of them, which go directly from the optic foramen to the globe of the eye, have received the name of *recti* muscles, and are distinguished, according to their positions, as *rectus internus*, *rectus externus*, *rectus inferior* and *rectus superior*.

A fifth muscle, the *superior oblique*, arises, like the foregoing, from the optic foramen, but, after passing along the inner and superior wall of the orbit, is reflected through a tendinous ring at the superior and anterior inner edge of the orbital cavity, and passing backward, is inserted into the upper and outer portion of the globe.

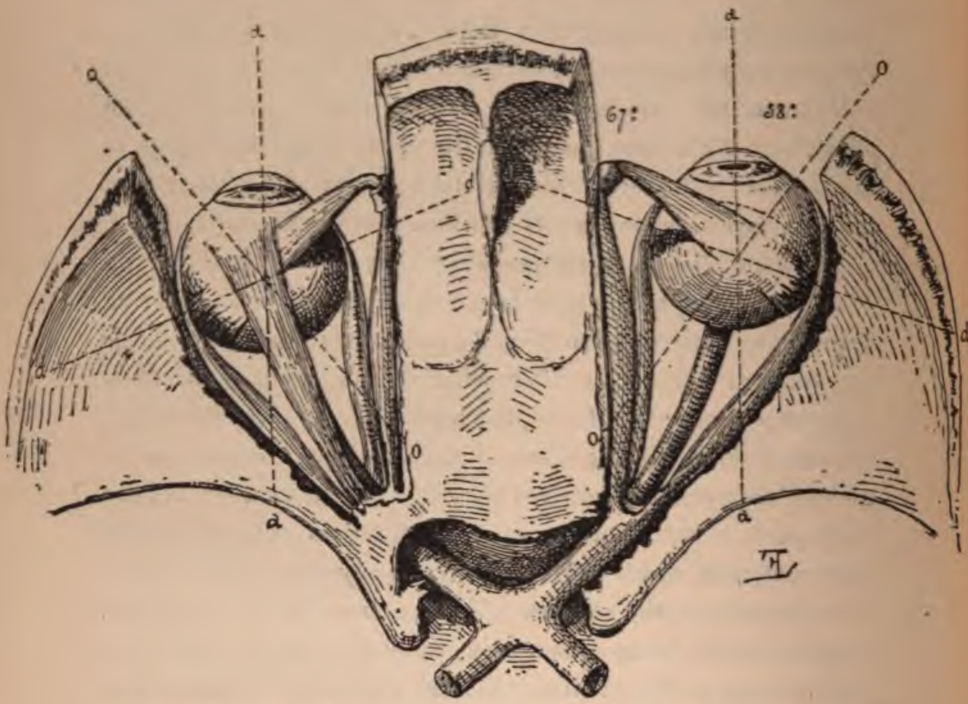
The sixth, the *inferior oblique*, arises from the anterior and inner part of the inferior wall of the orbit; it passes under the globe, toward the temple, and is inserted into its outer and posterior part.

The *rectus superior*, *rectus inferior*, *rectus internus* and the

obliquus inferior receive their nervous supply from the same source—the *motor oculi communis* (third cranial pair); the *superior oblique* and *rectus externus* each receives a special nerve, the former the *patheticus* (fourth pair), the latter the *abducens* (sixth pair).

The action of all these muscles is to turn the eye around a point

FIG. 3.



called the *centre of rotation*, situated on the antero-posterior axis of the globe, fourteen millimeters behind the cornea and ten millimeters in front of the posterior surface of the sclerotic, in the emmetropic eye, and corresponding to the point of intersection of the axes of rotation of the muscles of the eye. (See Fig. 3.)

From their points of insertion it will be readily seen that these six muscles form three pairs of *antagonistic muscles*, each of which is composed of two muscles turning the eye around the

same axis, but in opposite directions. Thus, the *rectus internus* and *rectus externus* turn the globe inward and outward about a vertical axis.

The axis of rotation of the *rectus superior* and *rectus inferior* (*d d* Fig. 3) is situated in a horizontal plane; it is not, however, strictly transversal, but forms, with the visual axis, an angle of about 67 degrees, the nasal extremity being in advance of the temporal. On this account these two muscles, apart from their principal action in elevating and depressing the cornea, have an effect to turn the eye slightly inward.

The axis of rotation of the *superior* and *inferior oblique* (*o o* Fig. 3) is likewise in a horizontal plane, but its direction is much more oblique than the foregoing, since it makes, with the visual axis, an angle of 38 degrees; its external or temporal extremity is in advance of its inner or nasal. These two muscles, therefore, incline the cornea outward, to a considerable degree, at the same time that they direct it, the first downward, the second upward.

In a normal condition these muscles, with the exception of the *internal and external recti*, never act singly, but are associated in divers manners for bringing the line of vision into different positions.

Thus, to look directly upward the *rectus superior* and *obliquus inferior* are united in action; to look directly downward, on the contrary, requires the combined action of the *rectus inferior* and *obliquus superior*. In this combination the deviation inward which would be caused by the *recti superior* and *inferior*, when acting singly, is counteracted by the opposing action of the *obliqui*. But, even when a single muscle suffices for any direction of the visual axis, there will be none the less a simultaneous contraction of all the other muscles, in order to maintain the eye in the position which it occupies. This tension of the muscles of the eye is, moreover, permanent, for on section of all the muscles the globe is seen to advance several millimeters. In all cases every movement of one

eye is normally accompanied by a simultaneous movement on the part of the other.

We will complete these preliminary physiological remarks by adding that in the investigation of the movements of the eye we take, as a normal point of departure, a position of the eyes which corresponds to a *minimum of innervation* of their muscles. In this position, which is called the *primary position*, the visual lines are directed straight in front, parallel to each other, and in the same horizontal plane.

It is the office of the muscles of the eye to *direct the two eyes to the point of fixation in such a manner that the image of the object fixed shall fall simultaneously on the macula lutea of each eye;* or, in other words, to *secure single vision with the two eyes.*

All departures from this rule indicate a derangement in their function.

All disturbances, therefore, in the movements of the eyes manifest themselves by the *impossibility to direct the two eyes together to the point of fixation.* This is manifested, on the part of the patient, by the *impossibility of simple binocular vision,* with the subjective symptoms of *asthenopia* and *diplopia;* on the part of the surgeon by the *deviation of the eyes* of the patient.

Whenever, therefore, a patient presents himself having his eyes turned from their normal position, that is to say, not directed together toward the object fixed, the following questions present themselves for solution, and their answers fix the diagnosis :—

1st. In what direction is the deviation?

2d. Which is the deviating eye?

3d. What is the degree of the deviation?

4th. To what cause is the deviation due?

In order to simplify the study of these questions, and at the same time to see the full extent of their bearing, let us take an example.

A patient comes to you and you find that the two eyes do not fix upon the same point. You should first ask yourself, In what

direction is the deviation? To take the most common instance, is it an excess of convergence or of divergence? It is an excess of convergence when the lines of vision or the visual axes cross in front of the point of fixation; it is an excess of divergence when they cross behind it. It is easy to determine either of these conditions. By causing the patient to fix an object, as the tip of the finger, for example, we see immediately whether the eyes converge too much or too little. In the example we have taken, let us suppose that the visual lines cross in front of the object fixed: the strabismus is convergent.

We must now determine which eye it is that deviates. In other words, an excess of convergence being demonstrated, to which eye is it due? A variety of cases may present themselves.

In the first place, the convergence may be produced either by a paralysis of the external rectus, or by a spasm of the internal rectus; the latter, however, being extremely rare.

Or, without a loss of mobility in any of the muscles there may exist a disturbance in their *relative movements*, a condition in which both visual axes are never directed to the same point, but are always crossed in front of the object, whichever eye is fixed on it. This is called *strabismus concomitans*. In this case the field of excursion of each eye is not diminished, but only displaced a certain number of degrees inwardly or outwardly.

Finally, strabismus may be only *apparent*. The centres of the cornea which guide our judgment in this matter, or rather the corneal axes, may converge or diverge, while the visual lines cross at the point of fixation. This is possible for the following reason: Even in the normal eye the visual lines do not, as a general rule, coincide with the axes of the cornea, but form with them an angle which is called *the angle a*. You can readily understand that this angle may be larger or smaller in different individuals.

Allow me, by way of parenthesis, to say a few words concerning

the angle *a*, of which you hear too frequent mention in ophthalmology not to have your ideas made definite in regard to it.

The angle a, as we have said, is *the angle formed by the optical axis and the visual axis* (Fig. 4).

The *optical axis*, in a dioptric system accurately centred, is the line *a a* which passes through the optical centres of the system, and is perpendicular to its surfaces. On the optical axis are situated the cardinal points, among others the *foci*, and the *nodal point* which represents the optical centre of the system. In the eye this optical centre is found in the posterior portion of the crystalline lens at *k* (Fig. 4).

FIG. 4.

The *visual axis* is the line which unites the point fixed (*V*) and the *macula lutea* (*m*). This line necessarily passes through the nodal point, and if the yellow spot were perfectly centred—if it were found on the optical axis—the visual axis and the optical axis would coincide. All objects fixed would then be on the optical axis; there would be no angle *a*. But the macula is not, as a rule, found on the optical axis; consequently this latter only coincides with the visual axis at the nodal point, and forms with it the angle *a*, the apex of which is the nodal point.

In the great majority of cases the yellow spot is situated to the outer side of the optic axis; the anterior extremity of the visual axis is therefore found on the inner side of the optical axis. In this case, we give the sign + to the angle *a* and call it *positive*.

This eccentricity of the macula may be so great as to produce in certain cases an angle *a* of 7° or even more. This is the case particularly in *hypermetropia*. In *emmetropia* it is smaller, generally from 3° to 4°.

Myopic eyes have a smaller angle *a*, and in high degrees of

myopia the yellow spot approaches the optic nerve to such an extent that it sometimes passes beyond the optic axis and is found on the *inner* side. In this case, the anterior extremity of the visual axis is situated to the outer side of the optic axis, and the angle a is *negative;* we give it, then, the negative sign —.

These facts, worked out by Helmholtz, Knapp, Donders and Doijer, and demonstrated by all who have occupied themselves with ophthalmometry, coincide perfectly with analogous facts which I have observed in my measurements of the distance between the papilla and macula lutea. I have measured the distance in 100 eyes during life, and have found a mean of 3.9 millimeters for the emmetropic eye, a greater distance for the hypermetropic eye, and a smaller for the myopic*. M. Dobrowolsky has obtained similar results.

You understand, now, how it is that when the angle a is positive the eyes appear to diverge, while they appear to converge in the opposite condition, notwithstanding the perfectly correct direction of the visual axis; the observer guiding himself by the centre of the cornea or the pupil through, or near to which, passes the optical axis.

For the determination of the angle α we generally use the ophthalmometer, which is admirably adapted for the purpose and very exact. But, as the instrument is not always accessible, I will describe a method much less exact but more simple, which we owe to Javal.

The eye to be examined is placed in the centre of a graduated arc like that of the perimeter. The eye is then required to fix a point (o) which corresponds to the apex of the arc, while you move along the arc a small flame, the reflection of which you observe in the cornea. At a certain degree of the arc the reflection of the flame will be just in the centre of the cornea. You find this point by following the progress of the flame, the eye being directly above or beneath it. When this point is found we know

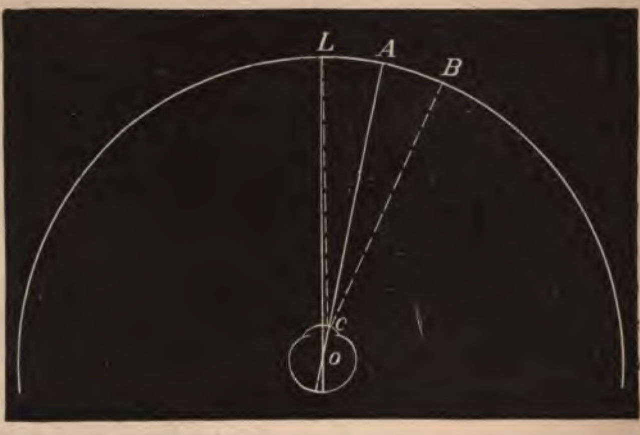
* Annali d'ottalmologia del Prof. Quaglino. Milano, 1872, I.

that the flame is situated on the optical axis, since it is directly in front of the centre of the cornea.

On the other hand, the visual axis of the eye passes through the point *o*, on which it is fixed. The eye being in the centre of the arc, the degree on which the flame is found measures the angle *a*.

A very simple and exact method for determining the angle *a*, and small degrees of strabismus, has been lately published by our assistant, Charpentier.* The plan, in brief, is as follows: The deviating eye is placed at the centre of the perimeter. At *o*, or on a line with it, is placed a small flame which the patient must accurately fix. The observer now moves along the graduated arc, the flame remaining in its place, until he sees, with one eye, the reflection of the flame at the apex of the cornea of the deviating eye. The angle which is thus formed is *double* the angle of the deviation of the eye.

FIG. 5.



In fig. 5, *o* is the deviating eye, which should, in its normal position, be directed toward *L*, but is now directed toward *A*. The angle *AoL* is the angle of the strabismus. The eye of the observer will see the reflection of the flame *L* from the centre of

* Annal. d'ocul., Jan.-Fev., 1878.

the cornea at B, when the ray Lc will be reflected from the cornea at an angle equal to the angle of incidence LcA. This last angle is almost the same as the angle LoA, which is the angle of the strabismus, and which is *half* the angle LcB.

Let us now return to our patient. We must first determine whether the strabismus is real or apparent. For this purpose we simply cover, with our hand, one of the eyes of the patient (or we can use with great advantage, for the same end, a piece of ground glass, which, applied close to the eye of the patient, allows the surgeon to follow the movements of that eye, but through which the patient is unable to see). We then cause the patient to fix attentively the forefinger of the other hand with the uncovered eye.

Now, while he fixes the finger closely we cover and uncover rapidly the other eye. If the eye first covered does not move while under the glass, or when the cover is removed, and sees the finger fixed, distinctly, the strabismus is only *apparent;* it is due to the angle α. Already under the hand or glass, that eye was directed to the object fixed by the free eye. We had attributed to a deviation of the visual axis that which was due to the convergence of the corneal axes.

In cases such as we have chosen (convergent strabismus), apparent strabismus will be exceptional, the divergence of the optic axes being, as we have seen, much more common than convergence. In our case, as soon as we remove the hand from the covered eye it makes a movement outward, in order to fix the finger. This shows that under the hand it had been directed too far inward. The strabismus is, therefore, *real.*

This fact being established, we have now to determine whether we have to do with a *paralysis of one of the external recti muscles,* or with a *strabismus concomitans.*

For this purpose we repeat, successively, on each eye, the procedure just detailed; we ascertain, by this means, whether the movement of readjustment is the same for each eye, in which case it will be a *strabismus concomitans;* or whether the deviation

is more pronounced on one side than on the other, as would be the case if there were *paresis*. In the latter instance the side of the paresis will be that on which the eye deviates the less under the ground glass or hand; in other words, that which makes the least movement of readjustment.

In our case, for example, the left eye deviates less than the right; it is, therefore, the one that is affected, and we have to do with a *paresis of the external rectus on the left side.*

This is explained as follows:—

The affected eye being directed, in a state of rest, too far inward, demands a contraction of its external rectus muscle to direct it to the object to be fixed. But, in order to produce that contraction, this weakened muscle requires an increased nervous impulse, which must be the greater in proportion to the degree of its paresis.

Now, the outward movement of one eye is accompanied by an inward movement on the part of the other. The contraction of the left external rectus being associated with that of the internal rectus on the right side, and as this latter is healthy, it will respond by a more powerful contraction.

Therefore, while the left eye, looking singly, makes an effort in an outward direction just sufficient to fix the object, the right is directed so strongly inward as to direct the line of vision to the inner side of the object fixed; when the right eye looks singly, as it demands for its sound muscle a nervous impulse less intense, the left eye will be deviated in a less degree. We can easily understand, then, that the deviation, and consequently the movement of readjustment, is greater for the healthy than the affected eye.

We are thus enabled to answer the second question: Which is the deviating eye? But our diagnosis will gain much in precision if we determine, at the same time, the *limits of excursion for each eye*, or, more properly, the *field of fixation.*

For this purpose we cause the patient to follow, with his eyes,

our finger, which we move to the right, left, upward, downward, to the furthest limits at which he is able to see it.

We thus compare the degree of *adduction* and *abduction* which each eye is capable of, and ascertain whether these movements are normal, as they are in the case of strabismus concomitans, or whether they are limited in one direction, as they would be in paresis or paralysis.

This is a rough means for determining the limits of the movements of the eyes, but more latterly I have been using a method in my clinic which enables me to measure, with a considerable degree of exactness, the *field of fixation* for each eye, both in healthy and pathological conditions. I put the head of the patient at the centre of the hemisphere represented on the walls by tangents (Fig. 8). The divisions are made in a horizontal and vertical direction, as well as in two intermediate directions. I cause the eye under examination to follow an object (test letters), which measures its minimum acuteness of vision, and which I move along the graduated lines. The patient indicates the points where it can no longer be seen distinctly. This marks, of course, the limits of excursion for the eye in the various directions followed. It is quite necessary to use as an object one of which the patient can distinguish the details, and not simply a piece of white paper or a flame of a candle, because, in order to determine with exactness the limits of movements, we must take as a basis the line of direct vision which falls on the macula lutea. If we use *indirect* vision we are sure to obtain a field of fixation larger than exists in reality.

The measurement can also be made by means of the perimeter and very small printed letters. This plan is especially applicable to myopes. The *field of fixation* is recorded on the same diagrams as the *field of vision* (Fig. 24). This method of determination is of especial importance when we have to do with the operation of strabotomy. By measuring, before the operation, the degree of strabismus and the contractile power of the weakened

muscle and its antagonist, and by repeating the measurements, after the operation, for some days, we can obtain valuable hints as regards the choice of an operative method and the amount of effect it is necessary to produce.

The mean measurements of the field of fixation, in a normal condition are—

Outward, 45°–50°.	Inward, 45°.
Upward, 35°–40°.	Downward, 60°.

In our case, we see that in making the patient look strongly to the right the pupil of the right eye is half hidden under the external angle of the lid, while in looking strongly to the left the external edge of the left pupil hardly reaches the outer angle on that side. As far as the power of convergence is concerned, it is preserved in an equal degree in the two eyes.

When the eye does not follow the object of fixation in a certain direction, but remains motionless, there is evidently a *complete paralysis* of the muscle which moves it in that direction. If, on the contrary, the eye is able to follow it up to a certain point, as in the case under consideration, the paralysis is *incomplete.*

When the eye arrives at the limit of the excursion which it is capable of, we frequently see it affected with oscillatory movements. This nystagmus is due to the fact that the muscles which, in a normal condition, are accessory to the paralyzed muscle endeavor, but without success, to supply its place. It is the two obliques, and possibly some isolated fibres of the recti inferior and superior, which produce this rotatory movement.

We are now prepared to study the third question: *What is the degree of the strabismus?*

You have seen that just now, in estimating approximately the deviation of the eye, I took as the fixed point of comparison the commissures of the lids. We are accustomed to express the strabismus by a linear measure which we note on the edge of the lid. Thus, we speak of a strabismus of 5 millimeters when the

point on the lower lid which corresponds, vertically, to the centre of the deviating eye is removed 5 millimeters from the point to which the centre of the pupil would correspond in a normal condition.

You will easily see, however, that this is a method of measurement extremely arbitrary. In the first place, what is more difficult than to determine exactly the points on the lid which correspond to the first and second positions?

Then, again, it is evident that rotary movements, such as those of the eye, should never be expressed by linear measure. When we have to do with displacements of the eye in its totality, we may say, the eye is moved 5 millimeters upward, downward, to the left, to the right, or forward. But the movements of the eyes are not displacements *en masse*, as we well know; they are rotations around a centre which remains fixed.

The expression of the excursive movements of the eye, as well as the limitation of such excursions, is given by the *arc* which the eye has described, or by its corresponding *angle*, the apex of which is at the centre of rotation of the globe.

You can see what errors we are liable to commit by measuring this arc by its projection on a straight line. You find one day, we will suppose, a strabismus of 5 millimeters; some time after it is 10 millimeters; would you say that it had doubled? Certainly not. You all know that the projection of equal arcs on a right line tangent to 0° diminishes more and more in proportion as the arcs approach to 90°, in such a manner that, in the case we speak of, the rotation of the eye has more than doubled.

Strabometry based on the measure of displacement of the centre of the pupil is, therefore, a method radically wrong, and it is astonishing that any one should propose a linear strabometer.

If we use a graduated rule across which we sight at the centre of the pupil, if we use the edge of the lid, which is neither a straight line nor an arc concentric with the excursions of the eye, or if we use the pretended strabometers, which consist of a

graduated disc having the curvature of the lids, we cannot hope to obtain a true measurement of the strabismus.

If you want only an approximate estimation the naked eye suffices. If you want an exact measurement, such as a conscientious observation of the progress of the affection demands, you must determine the *angle of the strabismus.*

I have defined this angle as follows*: *The angle of the strabismus is the angle which the visual axis of the deviating eye forms with the direction which it should have in a normal condition.*

We can determine this angle either *subjectively* or *objectively.*

The simplest manner of determining the angle of the strabismus is analogous to that we used in measuring the angle α (see Fig. 6).

We employ the graduated arc of the perimeter, at the centre of which we place the deviating eye c, the arc lying in the plane of the deviation. In the case we have taken as an example, the plane will lie horizontally. We then cause the patient to fix *with his two eyes* a distant object O, situated on the central radius coO. This is the direction which the deviating eye should have in a normal condition. What we have now to determine is the point x, at which the eye is in reality directed; the angle ocx formed by these two directions is the angle of the strabismus.

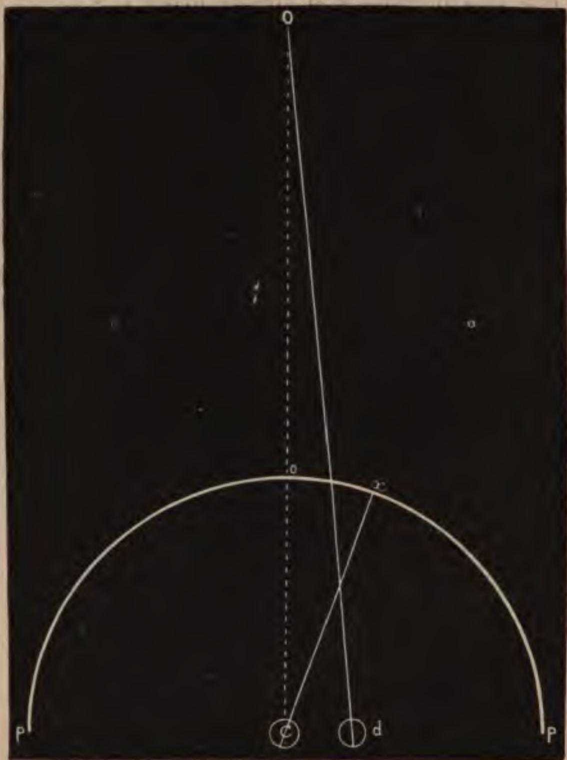
In order to obtain this latter direction, we have only to determine the visual axis of the eye. This, however, is by no means an easy matter. We, therefore, in practice remain content with the optical axis, which differs from the former, as we have seen, only by an angle (angle α) which, in comparison with the large angle of the strabismus, we can easily neglect. We, therefore, as has already been explained, move a candle along the arc until it comes to the point x where its reflection is in the centre of the cornea. We have then found the optical axis. The method of Charpentier, described on page 44, is most admirable for low degrees of stra-

* See *Handbuch der Gesammten Augenheilkunde*, von Gräfe u. Sämisch. Band III.

bismus. It does not answer so well as the foregoing in the higher degrees.

If the eye is deviated upward or downward, we proceed in the same way, placing the arc vertically.

FIG. 6.



When the deviation is not in a horizontal or vertical plane, but in an intermediate one, it will be with considerable difficulty that we can determine the precise meridian of deviation. In this case we measure separately the horizontal and vertical deviation. The result is then expressed as follows: the eye has a deviation of, say, 2° horizontally, and 10° vertically.

This manner of proceeding is the more legitimate since we follow the same principle, as we shall see further on, in determining

subjectively the degree of the strabismus, and frequently even in therapeutics, by combining a tenotomy of the superior or inferior rectus muscle with that of a lateral muscle.

After you have examined the deviation of the eye *at a distance*, it should be examined for the changes which it undergoes for *near vision*. For this purpose you simply bring the object *O* nearer, and proceed as before.

We frequently see the degree of the strabismus change with the convergence, and this fact furnishes us with important indications for operative procedure. If we find, for example, that a convergent strabismus diminishes very much in near vision, we should be careful to guard against too great an effect in the tenotomy, which would expose the patient to the evils of a painful or incomplete convergence.

LECTURE IV.

MOVEMENTS OF THE EYES (CONTINUED).—PRISMS.

GENTLEMEN:—The *objective* examination, of which we spoke in the last lecture, is the only one possible in cases where the deviating eye has lost its power of vision. Where the power of vision is still preserved this should be followed by the *subjective* examination.

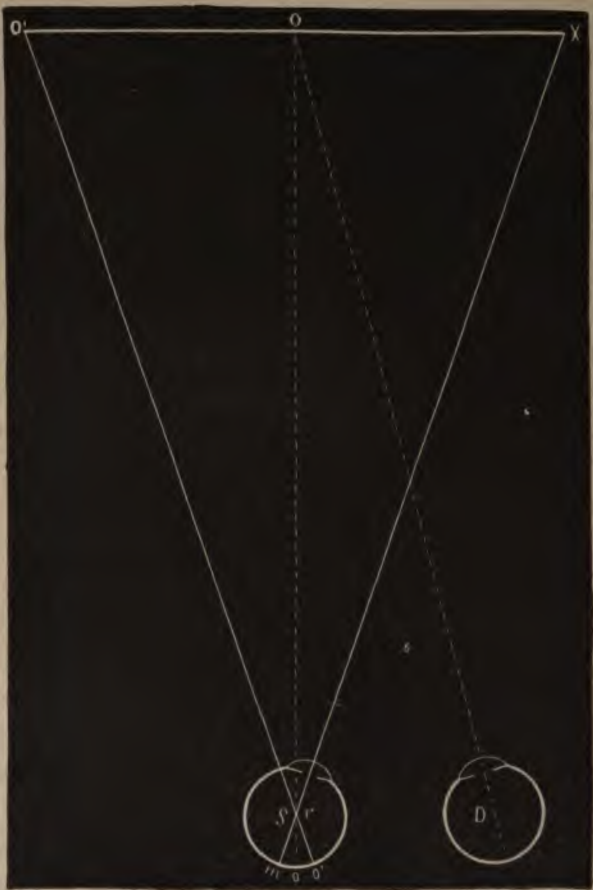
The principal subjective symptom of paralytic strabismus is *diplopia*. The diplopia is due to the fact that the retinal image of the object fixed, which, in the unaffected eye is formed on the macula, falls, in the deviating eye, on another part of the retina, and is projected as if the eye was in its normal position.

Let, for example, D (Fig. 7) be the right eye, and S the left deviating inward. The centre of rotation is in r, the macula in m; O is the object of fixation. The macula of the right eye is directed toward the point O; that of the left is directed toward the point X. The image of O, instead of being formed in the latter eye at m, is formed at o, and the eye S, which judges of the position of exterior objects as if it was in the proper position, projects its retinal image o in the direction from which the luminous rays should come, that, in a normal position of the eye, form their image in o.

In order to find this last direction we have, then, to suppose the eye returned to its normal direction, toward O. In this case the point m will be at o in front of O; and o will be displaced at an equal angle, and be found in o', and consequently the image will be projected in the direction o' O'. The object fixed is really, therefore, seen by the left eye S at O'. It is at O' that the

object should be found which forms its image, when the eye is normally directed, at o'. As this projection of the object is situated on the same side as the deviating eye, we call this form of diplopia *homonymous*.

FIG. 7.



The reverse of this takes place in *strabismus divergens*, when the eye is deviated outward. The anterior portion of the eye being then turned outward, the posterior part is turned in the opposite direction, and the macula is situated on the inside of the image of the object fixed; the latter is, therefore, formed on the

temporal part of the retina. Since, in a normal condition, it is the objects situated on the opposite side which form their images on the outer portion of the retina, the image is projected in the direction of the nose, that is to say, to the side of the unaffected eye, and the diplopia is *crossed.*

Hence the general law: *The diplopia is always in the direction opposite to that of the deviation: strabismus convergens, homonymous diplopia; strabismus divergens, crossed diplopia; eye deviated upward, image below; deviation downward, image above.* In the example which we have selected we will have, therefore, a homonymous diplopia.

The diplopia is only noticeable by the patient, and causes him to seek advice, when the deviation occurs suddenly, in consequence of an apoplexy, for example, or in rheumatic, syphilitic, or traumatic paralysis, etc. When the strabismus is developed slowly, especially in anisometropia, or when there is a notable difference in the acuteness of vision in the two eyes, the patient soon learns to suppress the image of the deviating eye and to look only with the other, whether there be a persistent deviation on one side, or each eye fixes in succession.

In these cases we sometimes bring out the diplopia by covering, with a colored glass of a strong tint, the eye which is habitually in use, and cause the patient to look at the flame of a candle placed at about two or three meters distance. This method has, moreover, the additional advantage of enabling us to control better the answers of the patient, since we always know to which eye to refer each image.

In our case, therefore, we will cover the right eye with a deep red glass, and the patient will say that he sees two flames, one, of the usual yellow color, to the left, the other, red, to the right. If the diplopia is not immediately pronounced we ask him the color of the flame he sees; he will probably answer "red." We then cover the right eye with the hand in order to draw his attention and fix it on the image of the left eye. By thus covering each

eye in succession you will soon find the patient observing two images.

There are cases, however, where, the strabismus not being very great, the patient succeeds in uniting the double images for some time, and sees only a single red flame.

You must not confound this single but binocular vision with monocular vision; because the flame seen by a single eye through the colored glass appears deeper in color than if seen by the two eyes together. In order to make the diplopia apparent we have only to place in front of the unaffected eye a prism, with its base turned upward or downward. The image is thus deviated vertically, and the fusion of this image with that of the other eye is made impossible.

The patient being no longer able to correct the horizontal diplopia, we can measure the lateral displacement without any difficulty.

The existence of diplopia being established, we now turn our attention to the determination of its *degree.* This is evidently in direct relation to the *distance between the double images.* It is hardly necessary to say that this distance increases with the degree of the strabismus; the greater the deviation of the eye the more is the corresponding image removed from that of the other eye.

Moreover, we find the diplopia greater *in the direction of the paralyzed muscle,* and less in the direction of the deviation. There is yet another method for determining which muscle is paralyzed. In our case, for example, the distance between the double images will increase in proportion as we carry the object of fixation to the left; it will diminish, on the contrary, in the right half of the field of fixation, and will cease altogether when the object coincides with the direction of the visual axis of the deviating eye. *The diplopia can, therefore, be made to serve as a measure of the strabismus;* only we must observe certain precautions.

In the first place, the diplopia varies, for the same deviation, according to the *distance between the object fixed and the eyes of the patient;* it increases and diminishes directly as this distance. You can easily convince yourself of this fact by producing an artificial diplopia by means of a prism. You will thus see that the two images approach to or remove from each other, as the object is approached to or removed from the eyes. If we would express the degree of the strabismus by the distance between the double images, it is necessary to state the distance between the object fixed and the eyes of the patient.

This method is the one generally adopted for the measurement of diplopia. It is said, for example, "here is a patient who, at a distance of two meters, has a diplopia of ten centimeters; it increases toward the left and amounts to thirty centimeters at a distance of two and a half meters." The diplopia for vision to the right, upward and downward, is determined in the same way. What strikes us at once in this manner of proceeding, is the large number of figures employed, and the confusion which they are liable to cause. But its principal defect lies in the fact that we express the value of angles in linear magnitudes. We have rejected linear strabometry in the objective examination; we should therefore, for the same reason, reject it in subjective strabometry by means of diplopia.

Here again we say: the line of vision is deviated to the right or left, *not for so many meters, but by so many degrees.*

Again, we do not content ourselves with indicating the distance between the double images, but measure, by the diplopia, the *angle of the strabismus.* According to the definition we have already given, the angle of the strabismus is the angle formed by the visual axis of the deviated eye with the direction which it should normally have.

Let us now refer for a moment to Fig. 7. We place a lamp at *O*, at a distance of three meters in front of the deviating eye *S;* *oO* is therefore the direction which the visual axis should normally

have. But the macula being found in m, mX is, in reality, the direction it has now. OrX is, therefore, the angle of the strabismus.

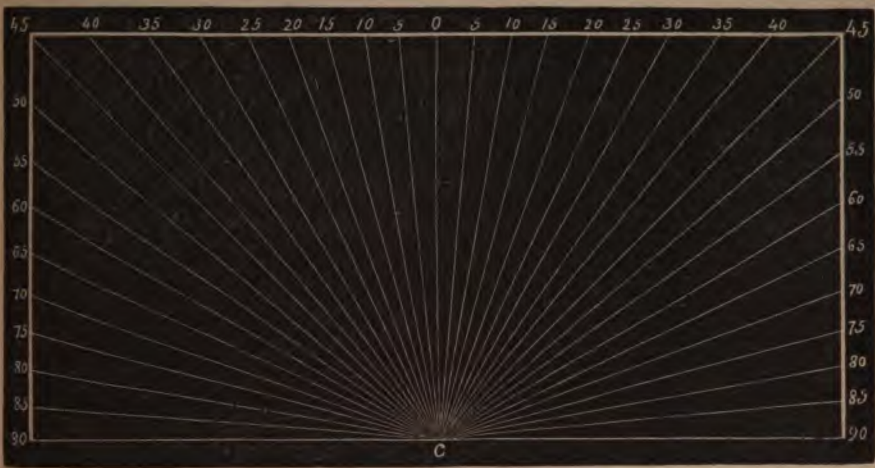
The image of O which the eye S receives falls on o; and as we have seen, is projected in O'. In order to find this direction we have supposed the eye to be readjusted to its normal position; the macula will then be at o and the image in o', having described an angle oo' equal to mo. The angle $O'rO$ is, therefore, equal to the angle OrX, the angle of the strabismus. Now, OO' is the tangent of this angle OrO'; *the distance between the double images is therefore the tangent of the angle of the strabismus*, and consequently we can use it to measure that angle. For this purpose we have simply to reduce the tangent to its angle.

I have made this reduction on tape for a distance (radius) of three meters. I place one end of the tape horizontally on a wall at the height of the patient's eyes, in such a manner that the zero shall be in front of the deviating eye (c, Fig. 8). The patient is placed three meters from this wall. To the right and left of zero the tape extends in a right line three meters, which corresponds to the tangent of an angle of 45°. At these points the tape is doubled on itself at a right angle, and fixed in that position on a chair or the adjoining wall. This, however, is generally unnecessary, since the field of fixation seldom exceeds forty-five or fifty degrees.

In this manner we have the tape in the form of a rectangle, and on this are marked, at intervals of five degrees, the points where the radii from the eye cut the tape. In other words, the divisions on the tape represent the tangents of the angles at intervals of five degrees, having their apices at the place occupied by the affected eye. Nothing is easier than to make this division. We have only eight tangents to determine. That of 45° is equal to three meters' length of radius. For angles greater than 45° we have only to double the tape on itself at 45° and mark on it divisions corresponding to those already marked, because

of the perpendicular direction which this portion of the tape will occupy.

FIG. 8.



For a radius of three meters the tangents are as follows:—

From 0 :	5° =	26 cm.	= 85°	from	90°.
" "	10° =	53 "	= 80°	"	"
" "	15° =	80 "	= 75°	"	"
" "	20° =	109 "	= 70°	"	"
" "	25° =	140 "	= 65°	"	"
" "	30° =	173 "	= 60°	"	"
" "	35° =	210 "	= 55°	"	"
" "	40° =	251 "	= 50°	"	"
" "	45° =	300 "	= 45°	"	"

For those who prefer a less distance than three meters I have reduced the tangents for a radius of 225 centimeters:—

From 0 :	5° =	19.6 cm.	= 85°	from	90°.
" "	10° =	39.6 "	= 80°	"	"
" "	15° =	60 "	= 75°	"	"
" "	20° =	82 "	= 70°	"	"
" "	25° =	105 "	= 65°	"	"
" "	30° =	130 "	= 60°	"	"
" "	35° =	158 "	= 55°	"	"
" "	40° =	189 "	= 50°	"	"
" "	45° =	225 "	= 45°	"	"

Those from 45° to 90° are repeated in the reverse order, starting at 45° on the perpendicular portion of the tape. A second tape is fixed vertically to the first, along a perpendicular passing through zero. The divisions should be made upward and downward in the same manner as in the preceding.

To further increase the exactness of my method, we can cover the wall with lines running horizontally and vertically through the points marked on the two tapes.

The affected eye thus finds itself, so to speak, at the centre of a graduated sphere, and in moving the candle flame along the divisions on the wall we can always mark in *degrees* the direction in which it appears to the eye.

The distance between the double images, indicated by the patient on the tapes, gives thus directly the angle of the strabismus.*

Suppose, for example, that in our case we have placed the flame at the point 0°. The right eye, covered with a red glass, sees the red flame at 0°, while the left eye, deviating inward, sees an ordinary flame on the point of the tape marked 5°. The angle of the strabismus is 5°. Let us now carry the flame to the left as far as 20°; the red image corresponds to 20°, while the image of the deviating eye falls, say, at 35°. We then say that, under an angle 20° to the left, the angle of the strabismus has become 15°. We follow the same course for deviations to the right, upward or downward.

Naturally, the lengths of the divisions increase from 0° to 45° in such a manner that if in direct vision and in vision at 45° we have the same distance between the double images, it does not follow that the angle of the strabismus is the same in both cases; it will be smaller in the second position, and the difference will still further increase as the angles pass 45°. Moreover, if the distance between the double images increases when the eyes are turned laterally, it is not always a sign of an increase of the strabismus in that direction. On the contrary, even if the angle of the

* **Landolt,** ***de la Strabometrie Ann. d'ocul. Juillet,*** **1875.**

strabismus remains the same for all movements of the eyes, the diplopia must necessarily increase in all the directions of the field of fixation. In such a case we have to do with a true strabismus concomitans, and the increase in the distance between the double images simply corresponds to the increase in the tangents of the same angle.

You thus see what an error we commit in taking for a direct measure of the strabismus the linear distance between the two images.

We remark, finally, that our method of measuring the angle of the strabismus is in no way more complicated than the linear measurement. In this latter you must likewise use a graduated tape. Now, the tangent division is as easily made as the linear, since you have all your lengths calculated in the table which we have just given. The final advantage of this method is that it gives results which can be compared with those furnished by the objective measurement, and allows one to be controlled by the other.

PRISMS.

We come now to an important method for correcting, and at the same time measuring, the strabismus, that is, the use of *prisms*.

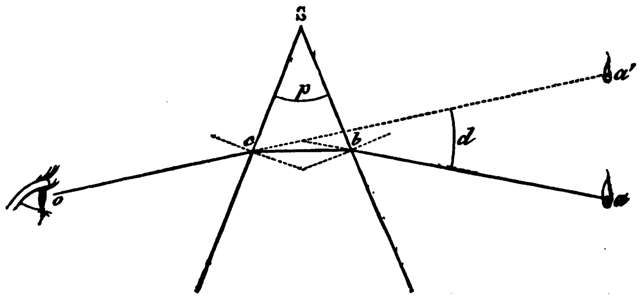
In looking through a prismatic glass we find that it produces an effect analogous to that of a deviation of the eye, that is to say, it causes a displacement of the objects looked at. It follows from this that, employed in a contrary sense, the prism would neutralize the diplopia caused by the deviation of an eye.

The action of a prismatic glass is explained as follows :—

A luminous ray coming from the point a (Fig. 9) and falling at b on a prism under an angle of incidence $a\ b\ d$, is deviated toward the normal, let fall at b, and crosses the prism in the direction $b\ c$. It leaves the prism inclining from the normal to the point c, and pursues its course toward the eye o in a direction $c\ o$, very

different from its primary direction *a b*. In order to see the point *a* the eye must be directed toward *c*, and *a* will then appear in *a'*. Therefore, when we look through a prism, the luminous rays being deviated toward its base, objects appear displaced toward the apex *S*.

FIG. 9.



This displacement evidently increases with the index of refraction of the substance of the prism, and with its *principal angle* (*p*). When the angle of incidence and the angle of emergence are equal the direction of the luminous rays in the interior of the prism is perpendicular to the line bisecting its angle; the angle of deviation (*d*) is, then, for weak prisms, equal to half of this latter.

The numbers inscribed on the prisms in our boxes of trial glasses indicate their principal angles. The prism marked No. 4 produces, therefore, a minimum deviation of 2°, and so on.

In order to show the application of prisms in practice we will take, as an example, the one already chosen, in which there is a convergent strabismus of the left eye. The patient has a homonymous diplopia, and the object fixed appears, for the left eye, displaced outward. A prism with its apex directed inward has the opposite effect, and displaces the object of fixation toward the nose.

Such a prism, properly chosen, therefore, brings the image which the left eye receives to its normal position, that is to say, it corrects the diplopia. In effect the macula is here displaced outward, the image of the object falling to the inner side of it.

The effect of a prism with its base directed outward will be to turn the rays coming from the object in that direction, and make them fall on the yellow spot.

By this means, the images of the object fixed being formed simultaneously on the macula of each eye, single and binocular vision is reëstablished.

Whence we obtain the general law: *The apex of the correcting prism should be turned in the same direction as that in which the eye is deviated*; deviation upward, apex upward; strabismus divergens, apex outward, etc.

The intermediate or oblique deviations can be corrected by single prisms placed obliquely; but we prefer, in the determination of the strabismus, to divide them into their two component parts, the one vertical, the other horizontal, and in their correction to use two prisms with their apices directed in the corresponding directions. We have no need, then, to determine directly the inclination of the prism. You can readily see that it is also possible to correct the diplopia by holding a prism in front of the unaffected eye and directing the apex in the contrary direction. We, however, prefer to correct directly the deviating eye, or to divide the correction equally between the two eyes.

The greater the deviation of the eye, and consequently the more considerable the diplopia, the stronger must be the prism. The angle of deviation of the prism should, therefore, increase with the angle of the strabismus, and, theoretically, the one should be a measure of the other, in such a manner, for example, as that a diplopia corrected by a prism No. 8 (having an angle of deviation of 4°) should correspond to a strabismus of 4°.

This method of measuring strabismus is, indeed, the one quite generally employed. But, in the majority of cases, the value of the angle of strabismus, determined objectively, is greater than the angle of deviation of the correcting prism.

This can be explained as follows: When, by the aid of a certain correction, the double images are brought very close to one

another, the tendency to single vision, so to speak, being awakened in the affected eye, it makes (with its weakened muscle) a last effort to correct the remaining diplopia, an effort which an instinctive knowledge of its powerlessness to do it prevented it from attempting when the diplopia was greater. Thus, the angle of deviation of the correcting prism is always less than the angle of the strabismus, but it approaches the more closely to it the more completely the muscle is paralyzed. The prism is, therefore, not a means perfectly exact for measuring strabismus.

Our trial boxes contain, generally, ten prisms, Nos. 2, 3, 4, 5, 6, 7, 8, 9, 10 and 15. For those cases where No. 15 does not suffice we simply combine a number of prisms together, always giving their apices the same direction. The number of the prism thus obtained would, of course, be the sum of the several prisms employed.

In order to produce, by a single instrument, a series of different prismatic effects, we superpose two prisms, of 15° each, for example. When their apices are directed in opposite directions the one neutralizes the other; when they have the same direction the one is added to the other, and they represent a prism of 30°. In turning the one on the other from the first position to the last we reproduce, successively, the action of all the prisms comprised between 0° and 30°. We obtain the same result by turning both in opposite directions. This principle was brought into practice formerly by Volkmann, and more recently by Crètés, in Paris.

Such an instrument is very easy to manipulate. The prisms, of a circular form, are moved by the aid of two springs which terminate in the frame and are controlled by a movable button pressed by the finger. A graduation marked on its frame serves to show the resultant action of the two prisms.

We will end this study with some remarks on the relative frequency of the paralyses of the different muscles of the eye, and the general laws presiding over the deviations which result from them.

The muscles which are the most frequently paralyzed singly, are the *external rectus* and the *superior oblique*, each supplied by a special nerve. The other muscles, internal recti, superior recti, inferior recti, and inferior obliques, all supplied by the *motor oculi communis*, are generally affected together, and are accompanied by paralyses of other muscles supplied by the same nerve; the levator palpebræ superioris, sphincter of the iris, and muscle of accommodation; constituting a very characteristic group of symptoms. We should say, however, that isolated paralyses of one of the muscles innervated by the third pair are not altogether rare.

Gräfe, whose authority on all points touching the troubles of motility of the eye is incontestable, has recorded, among 40,000 observations of eye affections, 183 cases of paralysis of the muscles, and, among this number—

105	paralyses	(isolated)	of		external rectus.
52	"	"	"		superior oblique.
10	"	"	"		rectus inferior.
9	"	"	"	"	superior.
5	"	"	"	"	internus.
2	"	"	"		inferior oblique.

I cannot here enter into a detail of the special symptoms offered by the paralyses of these different muscles. I would refer you, for that, to the Chart to be found at the end of the volume. But as all these symptoms, however various they may be, are under the dominion of a few general laws which follow from what we have been considering in this lecture, I will conclude by giving an exposition of them:—

A. In incomplete paralysis, the deviation which the unaffected eye undergoes while the affected eye fixes, is greater than the deviation of the affected eye during the fixation of the unaffected eye.

B. The impaired motility and the diplopia increase in the direction of the action of the paralyzed muscle. This is why, in

carrying the object of fixation in the direction of the paralyzed muscle, the image of the deviating eye appears to fly in front of that of the unaffected eye, and *vice versa.*

C. The image which the deviating eye receives is always projected in the direction of the paralyzed muscle. From this there result the following consequences :—

1st. The image of the affected eye is always found on the side opposite to the deviation of the cornea, or inclined in the direction the opposite of the pathological inclination of the vertical meridian.

2d. In fixing with the deviating eye alone, the patient falsely estimates the position of objects. When the sound eye is covered, and he is required to quickly strike an object placed within reach, he invariably misses it, and his hand goes to the side of the object corresponding to the paralyzed muscle. In paralysis of the external rectus, for example, he always strikes to the outside of the object. This phenomenon is manifested in a very curious manner when the patient walks with the sound eye covered. When you ask him to walk quickly toward a certain point in front of him, at first he will go considerably to the side corresponding to the affected muscle, and afterward, when he approaches near the object, suddenly turns toward it. This phenomenon is explained by the increase of nervous impulse necessary for the paretic muscle, in order to fix the object properly. Whence it comes that the patient judges the distance traveled over by the eye is much greater than it is in reality, that is to say, proportional to the nervous effort which the paralyzed muscle puts forth to direct the eye to the object fixed. He judges, therefore, the object to be situated to the outer side of its true position. It is, in part, to this cause that we can attribute the vertigo and the difficulty which certain patients experience in walking, especially when they have to descend steps. However, these troubles are due in part, also, to the diplopia.

LECTURE V.

MUSCULAR ASTHENOPIA.—TONOMETRY.

GENTLEMEN:—I cannot leave the consideration of the movements of the eyes without speaking of certain visual troubles which, at first sight, would appear quite independent of muscular function, but which, in reality, are in the most intimate connection with it.

A patient complains, for example, that his vision is fatigued very quickly; in the evening, especially, he cannot read nor write for any length of time, because when he has read for a short while the letters dance before the eyes. If he attempts to overcome this faulty vision he is successful only for a time, and invariably experiences, in consequence, pain in the eyes and head, especially the forehead. We have, in a word, the condition which is termed *asthenopia.*

Your first thought would be that the patient is hypermetropic or presbyopic, since the complaints of such patients are difficulty in vision near at hand and the impossibility to continue work for a length of time without pain. The cause of these phenomena is, as you are aware, an error of accommodation.

But on examination you find, on the contrary, a myopia, and frequently of a considerable degree.

You can here exclude presbyopia, because the patient, even without an effort of the accommodation, can see near at hand. You should now get a full and complete account of the symptoms of which the patient complains. Ask him, in particular, if he does not sometimes see the letters double when the eyes begin to ache. If he answers in the affirmative, as is usually the case,

your attention should be at once directed to the muscular system of the eye.

There may not, however, be the least trace of strabismus.

Nevertheless, cause him to fix an object, the forefinger, for example, with one eye, and bring it near the eye, the other being covered with the hand or a bit of ground glass, as in the examination of strabismus. You will now find, when the object is brought sufficiently close, that the eye under the hand or ground glass is deviated slightly outward. As soon as the eye is uncovered it makes a movement inward, in order to fix the object. In repeating the experiment on the other eye essentially the same conditions are found, and you have to do with a very common affection—an asthenopia caused by an *insufficiency of the internal recti muscles.*

The frequency with which this trouble is met with is not at all surprising. There are few muscles in the human economy so constantly in action as the internal recti.

All objects not situated at infinity demand for their fixation by the eye a convergence of the visual axes, requiring, of course, a greater or less amount of contraction on the part of the muscles in question. And the closer the object is approached the greater the amount of work required of them. This accounts for the fact that the fatigue—the expression of the feebleness of the two muscles—is manifested especially during near work; and also for the other fact that it is most frequently met with in myopes. It is, indeed, in these that the greater convergence is required, myopes being obliged to bring all objects very close to the eyes when they wish to see them distinctly, the reverse being the case with hypermetropes, who generally fatigue their internal recti much less.

For the same reason the asthenopia is felt more especially in the evening, because the patients have already been using their convergence during the whole of the day.

But it does not suffice to determine the deviation of the eyes

under the hand or ground glass; it is necessary to study it more closely and determine its degree. For this purpose we cannot use the objective mensuration, because there is generally no spontaneous deviation, and it is only manifest after considerable use, and in consequence of fatigue.

We must have recourse, therefore, to the *diplopia*. But again, this does not manifest itself spontaneously, especially for vision at a distance. In order to produce it we place in front of one of the eyes of the patient a prism of about 15°, with its apex directly upward or downward.

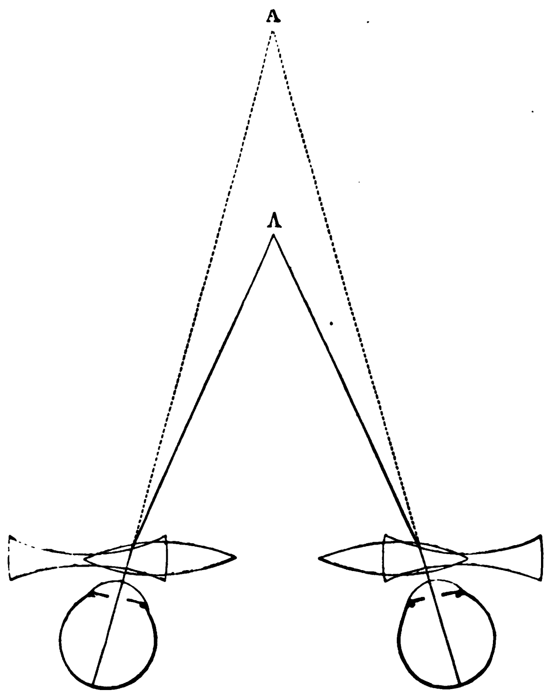
We have already seen, in considering strabismus of low degrees, that the super-position of images produced by the prism renders their fusion impossible. So the patient abandons his eyes to the natural play of their muscles, and then there is made manifest, in the case under consideration, a crossed diplopia. In order to prove it you place before the patient a sheet of paper on which is marked a black dot on a vertical line. You cause him to hold this at the distance at which he habitually reads.

The patient looking through the prism will, naturally, see two black dots, but not on the same vertical line; the left eye will see one of them to the right, and the right eye the other one to the left.

Crossed diplopia corresponds, as we have seen, to a divergence of the eyes. We seek, therefore, the prism which, held horizontally with its apex directed outward, again brings the two images on the single vertical line. It is solely for the purpose of facilitating the judgment of the patient as regards the position of the two images that we draw the vertical line through the dot. The patient has, then, only to indicate the moment when the double lines are exactly super-posed. You should take the precaution not to make the lines so long that, with the prism employed and the distance at which the experiment is made, they touch each other. The degree of insufficiency is determined by the number of the prism, held horizontally, which corrects the diplopia.

In order to correct the insufficiency of the internal recti we seldom have need to make a tenotomy of one of them. It generally suffices to employ a prism, the action of which is divided between the two eyes. If we find, for example, the insufficiency is counteracted by a prism No. 6 held in front of one eye, we place in front of each eye a prism No. 3 with the apex turned outward. We can also give to the two surfaces of the prisms a concave or convex curvature, in such a manner as to combine the action of spherical lenses with that of the prisms.

FIG. 10.



In the less pronounced cases, it will suffice simply to *separate* the *concave* glasses of myopes. The myope will then look mostly through the inner portion of the glasses, which will act as prisms with their bases turned toward the nose.

If an insufficiency of the internal recti is found in *hyperme-*

tropes or *presbyopes* who wear convex glasses, we can produce, on the other hand, the same effect by *approximating* the glasses; the external portions of the convex glasses will act as prisms with their apices directed outward. An examination of Figure 10 will show at once the mechanism.

We can easily obtain the prismatic effect by having the glasses so cut and fitted into the spectacle frame that the centres of the pupils shall fall to any desirable extent to the outer or inner side of the centre of the lens. We can thus attain the desired end and avoid the somewhat striking appearance which widely separated glasses present.

When the insufficiency of the internal recti is greater than 15°, and when the patient has passed the age of infancy, we can remedy the error by a delicately performed tenotomy of one of the external recti, or even of both. But we must be on our guard and not give too much effect to the operation; we should the rather leave a slight degree of divergence than run the risk of a possible convergent strabismus. Under such circumstances we prefer the *horizontal* incision in the subconjunctival tenotomy.

We meet, sometimes, with an *insufficiency of the external recti.* It is found nearly always in *hypermetropes.* It is much less frequent than that of the internal recti, and the consideration of it will not detain us, since it has the same symptoms, but *in an opposite sense,* as those we have been considering. The diplopia is homonymous, and in order to correct it we must *separate the convex lenses,* which then represent prisms with their apices turned inward; or, if we prefer, we give prismatic glasses turned in the same direction.

TONOMETRY.

The resistance which the eyeball opposes to external pressure is called the *intra-ocular tension,* and is a condition which sometimes assumes great importance in diagnosis and in treatment. As an example, I instance glaucoma. You are aware of the extreme

gravity of this affection, which, requiring prompt surgical interference, is very frequently misunderstood, especially at the beginning of its course. Now, glaucoma is characterized by an increase in the tension of the eye, and if the surgeon neglects the examination of the state of tension he will not recognize the affection in its first stage, and will not be prepared to combat it effectually.

The following case, which recently came under my observation, will serve to illustrate the importance of this examination. A poor patient came to me from the provinces, completely blind; she came, she said, to be operated on for cataract; and, in fact, the lenses in both eyes were somewhat turbid; and this was the more apparent on account of slight dilatation of the pupils. But, on an ophthalmoscopic examination, which was easily possible, in spite of the opacity of the lens, I discovered an excavation of both optic papillæ, and a complete atrophy of the optic nerves; the globe, on both sides, was as hard as stone; there was not a trace of perception of light. It was a case of double absolute glaucoma, and I was obliged to send the unfortunate woman home without any hope of recovery of her vision.

How did this come about? The affection was developed slowly, first in one eye and afterward in the other. When this woman was suffering she went to her physician, who told her that she had a cataract, but that she could not be operated upon until the cataract was ripe, that is to say, when she could no longer see at all. This happened, indeed, but at a time when she was beyond all hope of cure. If the physician had recognized the necessity of examining the tension of the eye, he would have recognized at once the nature of the trouble, and would have been able to save the eyes of his patient.

This, unfortunately, is not an isolated instance. Every ophthalmologist can cite analogous cases. It is important, therefore, that you should have your attention directed toward a symptom of so much consequence, and that you should know how to test the

intra-ocular tension. To do this, we proceed in very much the same manner as we make palpation. We place the tips of the forefingers lightly on the eye, covered by the upper lid, and press gently with each in turn, the other fingers resting against the edge of the orbit. This palpation should be made solely by the muscles of the fingers, and never by a pressure of the entire hand. During this examination the patient should look downward, in order that we may press only on the sclerotic; if the eye is directed upward, pressure is made on the cornea, which causes the tension to appear higher. For a similar reason the tips of the fingers should be applied above the tarsal cartilage, the thickness and resistance of which will give a false idea of the tension of the eye.

Coccius has proposed that the fingers be applied directly to the globe, the proceeding being, according to him, exceedingly well supported, if precaution is taken to moisten the fingers in tepid water. This is, of course, much more exact than the other method, on account of the variation in the volume and consistency of the lids in different individuals. However, when one has become used to making palpation through the lid, an exactness sufficient for practical purposes can be attained. The direct palpation can be reserved for doubtful cases, or those in which the lid is deformed.

For comparison you can take the eye of the opposite side when it is healthy; but it is best to take your own eye. This comparison you should never neglect.

Bowman, of London, has endeavored to find how many distinct degrees of intra-ocular tension he could recognize by the aid of the touch simply. By comparing his results with those of his colleagues, he concluded that there could be recognized three different degrees of augmentation and three of diminution of intra-ocular tension. Designating, then, by *Tn* the normal tension, he calls $T+1$, $T+2$, $T+3$, the various degrees of elevation, $T-1$, $T-2$, $T-3$, the different degrees of diminution of the tension of the eye.

In order to measure in a manner still more exact the intra-

ocular pressure, divers instruments, called *tonometers*, have been constructed. Most of these come from the Utrecht school, which has been especially engaged with this question. The principles of these instruments are either to measure the force necessary to produce a depression of a given depth in the globe, or to determine the depth of a depression produced on the globe by a given force. But all neglect, more or less, the *form* of the depression, which evidently varies much according to the degree of tension of the eye, and according to the resistance of the sclerotic. In a word, the instruments in question have not found as extended a practical application as was hoped for.

I shall therefore not enter into a description of them, and would refer those of you who are specially interested in the question to the description of a tonometer proposed by Snellen. That instrument unites the advantages of all other instruments proposed, and seems to fulfill the conditions necessary for an exact measurement.

The tonometer of Snellen consists of three metallic stems placed side by side in a tube, the two lateral ones perfectly movable, the third, central one, being connected with a spring, the strength of which is regulated at will. The two first form a vernier with the central stem, in order to indicate exactly how much this passes the others.

Before using the instrument we give to the spring the required force, and afterward apply to the globe the free extremities of the three stems, directed toward its centre. We then make pressure, and at the moment when this has attained the required force an escapement arrests the spring and fixes the stems in their relative positions.* We now have at once the force of the pressure, and the depth and form of the depression made on the globe. The form of this depression can be determined in a yet more exact manner by giving, successively, to the stems different degrees of separation.

* Weber.

At a reunion of physicians at Utrecht I proposed to construct a tonometer according to the following principle:—

Take a compressible ball the size of the eye and communicating with a receptacle which, as well as the ball, is filled with water. Apply this ball against the eye in such a manner that the latter shall make a certain depression in it; afterward increase, by any means whatever, a weight or spring, the pressure on the ball until this shall have recovered its original form; its tension will then equal that of the eye. This moment will be indicated by a return of the water contained in the ball to the level of that of the receptacle. The pressure which you have to make on the ball in order to restore it to its form will represent the intra-ocular tension.

I have not pursued this idea to its realization, but I give it to you, and think that, proceeding on this principle, we can make a good tonometer.

In practice, it is true, the educated fingers nearly always suffice to appreciate the intra-ocular tension; but who knows if, with the means of measurement rendered perfect, we should not obtain, on this point, new indications important for diagnosis and therapeusis? In any event, physiology demands a tonometer which can replace, without any lesion to the eye, the manometer which the experimenter is obliged to introduce into the anterior chamber in order to determine the pressure of the interior of the eye.

Among the diseases in which we especially find an increase of the intra-ocular tension, we mention, in the first place, glaucoma, of which it forms, as we have previously remarked, the principal symptom. It is this excess of pressure which produces the corneal trouble, the dilatation of the pupil, the pulsation of the veins and frequently of the arteries of the retina, but, first of all, the excavation of the papilla and the compression of the nervous fibres which causes the progressive contraction of the field of vision, and finally complete amaurosis. You are aware that a large iridectomy, peripherally situated, almost certainly arrests the progress of the disease.

The intra-ocular tension can also be increased by tumors developed in the interior of the eye or compressing it exteriorly. We observe, on the other hand, a diminution of tension when the membranes of the eye are thinned or ruptured in any place, and when there is a phthisis of the globe or a change in the conditions of filtration (exosmose and endosmose).

Detachment of the retina is nearly always accompanied by a diminution of intra-ocular tension. A diminished tension is likewise nearly always present in paralysis of the ophthalmic branch of the fifth pair. We see it again in cases of cyclitis, where it becomes an alarming symptom; it then indicates either the approach of an exacerbation of the trouble or the imminence of a sympathetic inflammation of the other eye. This is explained in the following manner: while the intra-ocular pressure is excessive the ciliary nerves are more or less compressed at their entrance into the sclerotic, and a propagation of the affection by these nerves is less possible; when, on the contrary, the tension diminishes, the ciliary nerves recover their conductibility, and with this the danger of sympathetic ophthalmia revives.

LECTURE VI.

REFRACTION.

GENTLEMEN:—The different parts of the apparatus of vision can be divided into three groups: The *first group* comprises the *external parts*, serving to protect the eye or to move it: lids orbit, external muscles, etc.

In the *second group* we range the parts transmitting the light, or the *dioptric apparatus*, serving to bring the optic nerve in relation with the external world.

The *third* comprises the *nervous apparatus* which receives and conducts to the central organ the luminous impressions transmitted by the media of the second group.

Up to the present we have been occupied with the parts which enter into the formation of the first group, and we have studied them with an eye single to the object to which these lectures are devoted, viz., to their importance in a diagnostic point of view.

We now enter on the consideration of the second group, still more important than the first. It is constituted, as I have told you, of the *dioptric apparatus*, and it is this which gives to the organ its properties of *refraction* and *accommodation*.

The dioptric apparatus is composed of the cornea, aqueous humor, the crystalline lens and vitreous humor. Our knowledge of these media is to-day quite advanced, though it has but recently become so, since it was only in 1611 that Kepler proved scientifically, for the first time, that the dioptric media produced images, real and inverted, on the fundus of the eye.

Moreover, it was only toward the end of the last century and the commencement of this, that Thomas Young and Volkmann laid the foundation of the theory of the refraction and accommodation of the eye. But it was Helmholtz who, by the aid of his ophthalmometer, determined with mathematical exactitude the dimensions, the radii of curvature and the indices of refraction of the various dioptric media. It was he and Listing who deduced the optical constants of the eye.

Donders, our illustrious master, has the merit of making a practical application of the labors of these learned physicists, by further developing the ideas in regard to the accommodation, and by establishing the theory of the anomalies of refraction and the principles of their treatment. You see, by this, that physiological optics is of a very recent date. Probably it is in part to this circumstance that the chapter of accommodation and refraction of the eye is generally regarded as the most difficult, most obscure, and especially the most theoretical in ophthalmology. As regards this last charge, it is not at all merited, and when once you are familiar with these questions, you will be astonished to see how many advantages essentially practical flow from them; how many patients, unsuccessfully treated by a hundred different collyria, or mutilated by inappropriate operations, can be restored to useful vision by the use of glasses properly selected and adjusted.

As to the reproach of abstruseness, it is explained less by the want of a knowledge of mathematics and physics than by the lack of a clear and accurate exposition of the subject.

I assure you that it is not necessary to be a mathematician in order to comprehend perfectly the most difficult problems of this portion of optics, and that the most elementary knowledge of algebra and physics suffices to master the principles of the refraction and accommodation of the eye, and to rationally correct their anomalies. It will be our endeavor, moreover, to treat the question as simply as possible, and to limit ourselves to that which is strictly necessary for practice.

The only thing which seems likely to complicate our task is that, just now, we find ourselves in a period of transition from the old to a new system of measurement of refraction, and this change must influence, more or less, our manner of investigating the subject. I allude to the

INTRODUCTION OF THE METRICAL SYSTEM INTO OPTICS.

It is not my purpose to treat of refraction and accommodation according to the old system, which is destined to fall into disuse, as well as the expressions in feet, inches and lines, on which it is founded. But we cannot dispense with some consideration of the old methods of measurement, and it is necessary for us to point out the differences between the old and the new systems. This is the more imperative as we have learned the elements of optics according to the old system. And this latter differs from the new system in many important particulars.

The refracting power of a lens depends, on the one hand, on the *index of refraction* of the glass of which it is made, and, on the other, on the *radius of curvature* of its surfaces.

The refracting power of a lens is the inverse of its focal distance. The more strongly the lens refracts the light the closer to it is its focus and the shorter its focal distance; inversely, the greater the focal distance the feebler the lens.

The formula expressive of the relations between the focal length F, the radius of curvature r, and the index of refraction n, of a bi-spherical lens, is—

$$F = \frac{r}{2\,(n-1)}.$$

A rational system of notation should indicate either the focal distance of the lens or its power of refraction.

The numbers which belong to the lenses of the old system (bi-spherical) indicate, in *inches, the radii of curvature* of their surfaces. Now, as the above formula shows us, the radius of

curvature does not tell us the refracting power of a lens, unless we know, at the same time, the index of refraction of the glass of which it is made.

In order to simplify the matter, a common index of refraction of 1.5 has been attributed to the glass of which lenses are made.

In this case the formula for F becomes $F = r$, that is to say, the focal distance and radius of curvature are equal when the index of refraction of the glass is 1.5.

It was generally accepted, therefore, that the number of the lens indicated both the radius of curvature and focal distance. Thus, for example, No. 6 was supposed to have a focal distance of 6 inches and a refracting power of $\frac{1}{6}$, etc.

But the index of refraction of the glass generally used in the manufacture of lenses is very seldom 1.5. It varies between 1.526 and 1.534. Consequently F is not always $= r$. On the contrary, the focal distance is nearly always less than the radius of curvature. The lenses of the old system are, therefore, stronger than they are represented if the numbers are intended to express their focal distances. Thus, in taking the index of refraction $= 1.53$, No. 36 has not 36″ focal distance, but only 34″, and its refracting power is $\frac{1}{34}$ instead of $\frac{1}{36}$.

The same is true for the other numbers. In the second column of the Table (page 87) will be found the numbers which express exactly the radius of curvature * of the lenses in the old system with the index of refraction which is most common, viz., 1.53.

It is certainly a great inconvenience of the old system that it gives to glasses numbers which in and of themselves mean nothing, or which, at best, only give approximatively the focal distance of the lens.

The old system has yet other inconveniences, and among them is the fact that *its unit is too strong.*

* The moulds which are used in the manufacture of lenses become worn in time, and the radius of curvature is thus materially modified.

In practice we have much more to do with the refracting power of a lens than with its focal distance. Now, supposing the number to give the focal distance of the lens, the refracting power will be the inverse of that number; and this being expressed in inches, the unit of the system was necessarily a lens of 1″ focal distance, with a refracting power of $\frac{1}{1}$. This lens is not found in boxes of trial glasses, and we seldom have need of it in practice, because it is too strong. We have need of lenses feebler in their refracting power than the unit, and it is for this reason that all our lenses are represented by *fractions* of the unit. *

This is inconvenient, because the combination of lenses, and all calculations relative to the values of the refraction which we have to make in the daily routine of practice, must be made in fractions, and thus become complicated.

Moreover, *the inch is not a uniform measure* corresponding to a standard universally adopted; it is a measure arbitrarily chosen, and different in different countries. Thus, we have the Paris inch, the English inch, the Austrian inch, etc., all of which differ from one another.

Thus—

1″ Paris	=	27.07 mm.
1″ English	=	25.3 "
1″ Austrian	=	26.34 "
1″ Prussian	=	26.15 "

Spectacles are manufactured in accordance with each of these measures. A lens No. 5, made in France, does not correspond, therefore, to a No. 5 English, Austrian or Prussian lens.

Finally, the intervals between the different numbers of the old series are very unequal, and it was difficult to estimate their value, because it must be done through the subtraction of fractions.

*If we had need of lenses of ½ or ¼ inch focal distance, they would be represented by $\frac{1}{\frac{1}{2}}$, $\frac{1}{\frac{1}{4}}$, etc.; that is to say, by the whole numbers 2 and 4, etc.

In the following table is this old series, with the intervals expressed in dioptries :—

Number.	Interval of Refraction in Dioptries.	Number.	Interval of Refraction in Dioptries.
72		10	
	0.11		0.45
60		9	
	0.16		0.54
48		8	
	0.12		0.70
42		7	
	0.15		0.43
36		6½	
	0.22		0.50
30		6	
	0.33		0.60
24		5½	
	0.33		0.71
20		5	
	0.21		0.87
18		4½	
	0.29		1.02
16		4	
	0.15		1.47
15		3½	
	0.18		0.8
14		3¼	
	0.21		1.0
13		3	
	0.26		1.4
12		2¾	
	0.30		1.3
11		2½	
	0.34		1.7
10		2¼	
			2.2
		2	

These various inconveniences have been felt for a long time by ophthalmologists. Thus, Professor Donders has not used, as a measure of the accommodation, a focal distance, but has taken as a unit of refraction a lens with a refracting power of $\frac{1}{24}$ of the old system. On this unit he has based his diagram representing the amplitude of the accommodation.

Burow, who was among the first to occupy himself with this question, already in 1863 had a series of lenses which were regularly progressive, with an interval of refraction equal to a lens of 120″ (3 meters) focal distance.

Giraud-Teulon pointed out* how much the calculations which are to be made in the determination of the refraction and accommodation are simplified, when we express in whole numbers, not the focal distance, but the refracting power. By adopting, as a unit, a refracting power of $\frac{1}{216}$ (216″ focal length), Giraud-Teulon made a great step toward procuring for us the introduction of a new system in the numbering of glasses.

Finally, at the International Congress of Ophthalmology, held at Paris in 1867, Javal, in the name of many colleagues, proposed to number lenses no longer according to their radii of curvature, but by their focal length, and to use, as a basis of measurement of that distance, the *meter* instead of the inch.

On the same occasion Nagel, recognizing as well as Javal the necessity of introducing the metrical system in the numbering of glasses, again brought forward his plan† to use, in giving numbers to the lenses, not their focal distance, but their refracting power.

This method of numbering necessitated the choice of a unit of refraction, and Nagel proposed as such a unit a lens of *one meter* focal distance, and offered to the Congress exactly the series of lenses which we now employ.

This proposition was, however, not immediately adopted. But a commission, composed of Messrs. Becker, Donders, Giraud-Teulon, Javal, Leber, Nagel, Quaglino and Sœlberg-Wells, was appointed to examine this question, and at the Ophthalmological Society held in Heidelberg in 1875, and at the International Medical Congress held in Brussels in the same year, a new system of numbering glasses was adopted, which is now in use, and which, as we shall see, is precisely the one proposed by Nagel, and for a long time contended for by him alone. The principles of this new system are as follows:—

1st. Numbering the lenses according to their *refracting power*.

* Giraud-Teulon in Makenzie's "Traité pratique des maladies des yeux," 4th edition-Supplement, 1865.

† Nagel's Compendium der Refractions Anomalieen, p. 30, 1866.

2d. The choice of a unit sufficiently feeble, so that the numbers of the lenses generally in use should be expressed in *whole numbers* and not in fractions.

3d. The substitution of the *meter* for the *inch* as a basis of measurement of the focal distances of the lenses.

4th. Having the intervals increase gradually from the feebler to the stronger numbers.

The unit of the new system, No. 1 of the new series of lenses, *is a lens of* 1 *meter focal distance*. It is called a DIOPTRY (D) in accordance with the proposition of Monoyer. Its refracting power is, therefore, represented by $\frac{1}{1\text{ m}}$.

We call No. 2 the lens which has two units of refraction, two dioptries, $\frac{2}{1\text{ m}} = 2$ D; No. 3 has three dioptries; No. 4 has four, and consequently is four times as strong as No. 1, ($4 \times \frac{1}{1} = 4$,) and so on.

By thus following the simple cardinal numbers we obtain a series of lenses having the same interval, namely, one dioptry.

It has been found in practice, however, that we have need of lenses weaker than one dioptry. And for this reason there have been admitted into the scale fractions of a dioptry. We have lenses of $\frac{3}{4}$ D (0.75 D), $\frac{1}{2}$ D (0.5 D) and $\frac{1}{4}$ D (0.25 D).

Quarters of a dioptry have likewise been introduced between the weaker numbers of the series up to No. 2.5, and half dioptries from No. 2.5 up to No. 6. In the higher numbers of the series the interval of one dioptry is too small, a slight variation in the distance between the lens and the eye producing an effect greater than 1 D. No. 19 has, for this reason, been suppressed. The series found in column V of the Table has been adopted for the trial cases in use in practice.

The *interval* which separates any two adjacent numbers of the series, as is seen, is 1, or $\frac{1}{2}$, or $\frac{1}{4}$ of the unit, that is to say, of one dioptry; and in all cases the interval between any two numbers can be readily found by the simple subtraction of whole numbers or decimals. We can thus easily tell by how much one glass is

weaker or stronger than another, or how much an ametropia or presbyopia has increased or diminished.

Focal distance. It is very easy to find the focal distance of the lenses of the new system, when we remember that the focal distance is the inverse of the refracting power. We have, for example, a lens of a power of 4 D, $\frac{4}{1\text{ m}}$ or $\frac{4}{100\text{ cm.}}$; its focal distance is $= \frac{1\text{ m}}{4}$ or $\frac{100\text{ cm.}}{4} = 25$ cm. 6 D corresponds to $\frac{100\text{ cm.}}{6}$ $= 16$ centimeters focal distance, etc.

We can determine with the same facility the *number of the lens*, that is the number of dioptries, corresponding to a given focal distance. Since the dioptry is the inverse of the focal distance, the number is found by means of a fraction whose numerator is one meter or 100 centimeters, and the denominator the focal distance.

To find, for example, the number of dioptries (d) corresponding to a focal length of 40 centimeters, we write—

$$d = \frac{1}{0\text{ m}.4} \text{ or } \frac{100}{40} \doteq 2.4\text{ D}.$$

In order to express in a general formula the above facts we call the number of dioptries d, the focal distance F, and then write—

$$d = \frac{1}{F},\ F = \frac{1}{d},\ dF = 1.$$

THE RELATIONS OF THE OLD SYSTEM TO THE NEW.

When we wish to know the focal distance in inches of a lens of a given number of dioptries, we have only to bear in mind that 1 meter = 37″ of Paris, or 39.5″ English.

Therefore :—

1 D or $\frac{1}{100\text{ cm.}} = \frac{1}{37''}$	Paris,	$= \frac{1}{39.5''}$	English.
2 D or $\frac{2}{100\text{ cm.}} = \frac{2}{37''}$ or $\frac{1}{18.5''}$	"	$= \frac{2}{39.5''}$ or $\frac{1}{19.7''}$	"
3 D or $\frac{3}{100\text{ cm.}} = \frac{3}{37''}$ or $\frac{1}{12.3''}$	"	$= \frac{3}{39.5''}$ or $\frac{1}{13.1''}$	"
dD or $\frac{d}{100\text{ cm.}} = \frac{d}{37''}$	"	$= \frac{d}{39.5''}$	"

That is to say, we must divide 37″ (or 39.5″) by the number of dioptries, in order to obtain the equivalent refracting power in inches. The denominator of the fraction then gives the focal distance of the lens, expressed in inches. The numbers of the new system thus obtained are the figures in columns VII and VIII of the Table.

We proceed, in an inverse manner, to find the equivalent in dioptries of a lens whose focal distance in inches we know. Let the focal distance of this lens be expressed by p''; its refracting power will be $\frac{1}{p}''$, and this lens will represent as many dioptries as its refracting power contains $\frac{1}{37}$ (Paris) or $\frac{1}{39.5}$ (English). In order to find the number of dioptries it is necessary, therefore, to divide $\frac{1}{p}''$ by $\frac{1}{37}$ (Paris). Now, to divide $\frac{1}{p}''$ by $\frac{1}{37}$ is the same as dividing 37 by p'' $\left(\frac{\frac{1}{p''}}{\frac{1}{37}} = \frac{37}{p''}\right)$. We have, therefore, only to divide 37 (or 39.5 when using English inches) by the number of inches focal distance in order to obtain its equivalent in dioptries. Thus, a lens of 17″ Paris, focal distance will be $\frac{37}{17} = 2.25$ D; 17″ English, $= \frac{39.5}{17}, = 2.3$ D.

It is in this way that we can transpose the lenses with the old numbers to the new series when the index of refraction of the glass is 1.5, or when the radius of curvature and the focal distance are the same. When such is the case we have only, when we wish to find the number of D corresponding to any number of the old system, to divide 37 (Paris) or 39.5 (English) by that number.

But when, as is most commonly the case, the index of refraction is greater than 1.5, and consequently the radius of curvature is not equal to the focal distance, we divide 37 or 39.5, not by the number which the lens bears, but by its determined focal distance. For a lens with an index of refraction of 1.53 we do not take the number in the first column of the table, but that in the second, which expresses the focal distance corresponding to that index of refraction. In this manner we find, as equivalents of the old series, the numbers of D contained in columns III and IV.

TABLE

Showing the Relations between the Old and New Systems of Numbering Glasses.

OLD SYSTEM.						NEW SYSTEM.					
I.	II.	III. Paris Inches.		IV. English Inches.		V.	VI.	VII. Paris Inches.		VIII. English Inches.	
Number of Glass.	Focal Distance in Inches (English or Paris), with an Index of Refraction = 1.53.	Focal Distance in Millimeters.	Equivalents in Dioptries.	Focal Distance in Millimeters.	Equivalents in Dioptries.	Number of Glass.	Focal Distance in Millimeters.	Focal Distance in Paris Inches.	Corresponding No. in Old System, with an Index of Refraction = 1.53.	Focal Distance in English Inches.	Corresponding No. in Old System, with an Index of Refraction = 1.53.
72	67.9	1837	0.54	1717	0.58	0.25	4000	148.	156.	158.	167.48
60	56.6	1523	0.65	1431	0.69	0.5	2000	74.	78.	79.	83.74
48	45.3	1225	0.81	1146	0.87	0.75	1333	49.	52.	52.3	55.43
42	39.6	1072	0.93	1001	0.99	1.	1000	37.	39.2	39.5	41 87
36	34.	920	1.08	860	1.15	1.25	800	29.6	31.2	31.6	33.49
30	28.3	766	1.30	715	1.3	1.5	666	24.6	26.1	26.3	27.87
24	22.6	612	1.63	571	1.7	1.75	571	21.	22.3	22.5	23.85
20	18.8	509	1.96	475	2.01	2.	500	18.5	19.5	19.7	20.88
18	17.	460	2.17	430	2.32	2.25	444	16.4	17.4	17.5	18.55
16	15.	406	2.46	379	2.63	2.5	400	14.8	15.6	15.8	16.74
15	14.1	383	2.61	356	2.8	3.	333	12.3	13.	13.16	13.94
14	13.2	357	2.8	333	3.	3.5	286	10.5	11.1	11.2	11.87
13	12.3	332	3.	311	3.2	4.	250	9.23	9.78	9.9	10.49
12	11.3	306	3.26	285	3.5	4.5	222	8.22	8.7	8.8	9.32
11	10.3	280	3.56	260	3.85	5.	200	7.4	7.8	7.9	8.37
10	9.4	254	3.9	237	4.22	5.5	182	6.71	7.1	7.18	7.61
9	8.5	230	4.35	215	4.65	6.	166	6.15	6.5	6.6	6.99
8	7.5	203	4.9	189	5.29	7.	143	5.29	5.59	5.64	5.67
7	6.6	178	5.6	166	6.02	8.	125	4.6	4.89	4.9	5.19
6½	6.13	166	6.02	155	6.45	9.	111	4.11	4.35	4.4	4.66
6	5.6	152	6.52	141	7.09	10.	100	3.7	3.91	3.9	4.13
5½	5.2	140	7.12	131	7.64	11.	91	3.37	3.56	3.6	3.81
5	4.7	127	7.83	118	8.47	12.	83	3.07	3.26	3.3	3.5
4½	4.2	115	8.70	106	9.43	13.	77	2.84	3.01	3.	3.18
4	3.8	102	9.72	96	10.4	14.	71	2.63	2.8	2.8	2.97
3½	3.3	89	11.2	83	12.	15.	67	2.47	2.60	2.6	2.76
3¼	3.1	83	12.	78	12.8	16.	62	2.3	2.44	2.5	2.65
3	2.8	76	13.	70	14.3	17.	59	2.18	2.30	2.3	2.43
2¾	2.6	70	14.4	65	15.3	18.	55	2.03	2.17	2.2	2.33
2½	2.36	64	15.7	59	16.9	20.	50	1.85	1.95	1.9	2.01
2¼	2.1	57	17.4	53	18.8						
2	1.88	51	19.6	47	21.2						

We can accomplish the same thing in a more simple manner when, for a given index of refraction, we calculate at first the dioptric equivalent.

Thus, for an index of refraction of 1.53, a lens of $37'' = 1$ meter focal distance, should have a radius of curvature of $39.15''$ (Paris,) and should have, therefore, the number 39.15. In order to find

the equivalent, not of the focal distance, but of the *number* of the lens, we write—

$$1\ \mathrm{D} = \tfrac{1}{39.15},\ 2\ \mathrm{D} = \tfrac{2}{39.15},\ d\ \mathrm{D} = \tfrac{d}{39.15}.$$

Under the same circumstances a lens of 1 meter focal distance = 39.5 English inches should have a radius of curvature of 41.87 inches.

$$1\ \mathrm{D} = \tfrac{1}{41.87},\ 2\ \mathrm{D} = \tfrac{2}{41.87},\ d\ \mathrm{D} = \tfrac{d}{41.87}.$$

Inversely, to find the number of dioptries which corresponds to a *number* of that series, we will have to divide 39.15 by the number. Thus—

No. 13 will give $\frac{39.15}{13} = 3.01$. D.
No. N " $\frac{39.15}{\mathrm{N}}$ dioptries.

But the number 39.15 is very difficult to divide, and we can, without any considerable error, replace it in practice by No. 40 (for French inches), and consider the dioptry as corresponding to No. 40 French, or No. 42 English of the old system.

The numbers of the new system become larger with the refracting power of the lens, while those of the old system become smaller. The two numbers progress, therefore, in opposite directions, and 2 D corresponds to the No. $\frac{40}{2}$ = No. 20 of the old system; 3 D = $\frac{40}{3}$, = 13.3 of the old series; 4 D = $\frac{40}{4}$, = 10, etc.

Now, if we call the number of dioptries d and the number of the old system N we shall have the equation—

$$\mathrm{N} = \frac{40}{d}.$$

Inversely, knowing the old number, if we desire to find the number of dioptries corresponding to it, we simply reverse the equation—

$$d = \frac{40}{\mathrm{N}}.$$

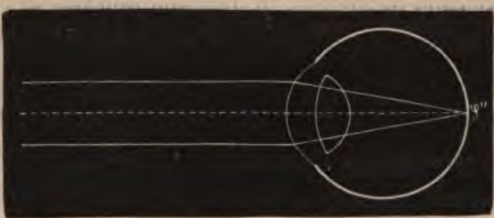
Example: the old No. 20 (Paris) corresponds to

$$d = \frac{40}{20} = 2\ \mathrm{D}.$$

This question being solved, we can now return to our principal subject, the *refraction of the eye*, and explain the elementary principles involved in it. You will be better able to understand these fundamental principles, however, when we come to apply them to practice, in determining the nature of the refraction and accommodation and the degrees of ametropia.

The dioptric apparatus of the eye comprises, first, the *cornea*, the radius of whose curvature is about 8 millimeters. It is separated from the crystalline lens by the anterior chamber, filled with the *aqueous humor*, and having a depth of 4 millimeters. The anterior surface of the crystalline lens has a radius of curvature of 10 millimeters, the posterior surface a radius of 6

FIG. 11.



millimeters; its thickness is 4 millimeters (see Fig 11). After having crossed these media the light pursues its way in the *vitreous humor* up to the retina. The index of refraction of the aqueous and vitreous humor is, on an average, $\frac{103}{77}$, and that of the lens $\frac{16}{11}$.

The figures which we have just given have been determined by Listing, Helmholtz and Donders. They have not, however, an absolute value, and, within a certain measure, may be found different in different eyes. Helmholtz has, indeed, modified the above numbers somewhat, but we, nevertheless, give them as they appeared in his first work, because, being round numbers, they are more easily managed.

The office of the dioptric apparatus of the eye is to produce on the retina distinct images of external objects. You are already

aware that the images are inverted, as all real images formed by a collective system are.

The question has been frequently discussed as to why we see those objects upright whose images are inverted on the retina. At the beginning of the last century, even, there were some physiologists who denied the fact, and who, not being able to explain how the inverted images were projected upright externally, maintained that the retina received the image upright. I remember to have found, for example, in a medical work of Stephen Blanquard, published at the commencement of the eighteenth century, an engraving which shows how images which are inverted by the lens are again inverted, that is to say, are set upright, by the vitreous humor.

The explanation of the fact in question appears to me, however, to be very simple. Suppose one born blind to suddenly receive sight. Far from having a correct idea of what he sees, he does not at first at all properly interpret the images formed on the retina. He sees neither upright nor inverted; he does not see at all, so to speak, although objects are painted on the retina. Indeed, he has not, as yet, the mental conceptions which correspond to the impressions made on the percipient elements of the retina. It is only by experience, by comparison of the impressions of touch, hearing, and of the other senses with his visual impression, that he comes to bring the retinal image in relation with the external object. Experience teaches him, among other things, that in order to observe the upper extremity of an object it is necessary to direct the eyes upward, and in order to observe the lower extremity he must direct them downward, and in this manner is established the interpretation of the position of objects by means of the movements of the eyes. It would be entirely useless for the individual to receive the image upright, since he would not find it easier to interpret it thus than if it were inverted. In any case he would be compelled to resort, for its interpretation, to *experience.*

What is of much more importance than the *posture* of the retinal image is its *distinctness*. If the image is not distinct the eye cannot see clearly. Now, in order that the image be distinct the retina must lie exactly at the place where the image of the dioptric system is formed, for, as with all dioptric systems, the eye can furnish distinct images only of objects situated at one and the same distance, unless its dioptric apparatus is capable of alteration. Fortunately, however, we can see equally well at different distances.

The cause of this is found in the *accommodative power* of the eye. Accommodation, of which we shall speak more fully further on, consists in an increase of the convexity of the lens, caused by a contraction of the ciliary muscle. Accommodation, therefore, *increases* the refracting power of the eye, and adapts it to objects nearer at hand.

The eye, *in a state of repose*, is adapted to the furthest point at which it is able to distinguish objects, that is to say, to its *punctum remotum*. Now, the greatest distance at which an object can be situated, and at which we have need to see, is *infinity*. For this reason we consider as *normal* an eye which, in a state of rest, sees at an infinite distance, and we call that condition *emmetropia*.

EMMETROPIA.

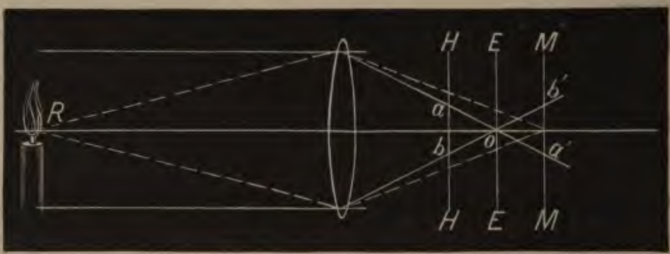
The emmetropic eye is, therefore, one which, in a condition of rest, sees at an infinite distance; and since, in order to see clearly, it must have an image formed distinctly on its retina, the retina of the emmetropic eye should be found where the rays coming from infinity, that is to say, *parallel* rays, are brought to a focus by the dioptric system of the eye. It is at the principal focus of this system that the rays coming from infinity are brought to a focus. We can, therefore, define an emmetropic eye as follows :—

The emmetropic eye is one the retina of which is found at the

principal focus of its dioptric system, or one which unites parallel rays on its retina, or, expressed in another manner, the punctum remotum of which is situated at infinity.

We can represent the emmetropic eye by a convex lens at the focus of which is a screen which corresponds to the retina (E E Fig. 12). The sun, or any object far removed, forms a distinct image on the screen.

FIG. 12.



For simplicity, we choose as an object the flame of a candle placed at a distance of about 5 meters; this being, for the eye, a distance sufficiently great for rays coming from it to be considered parallel.

AMETROPIA.

All eyes which are not emmetropic are *ametropic*. In *ametropia* parallel rays are not united on the retina, but either in *front of* or *behind* it. If we advance the screen toward, or withdraw it from, our lens, we will find that the image of the flame becomes diffuse (a b, b' a', *Fig.* 12). The same phenomenon occurs in the eye.

HYPERMETROPIA.

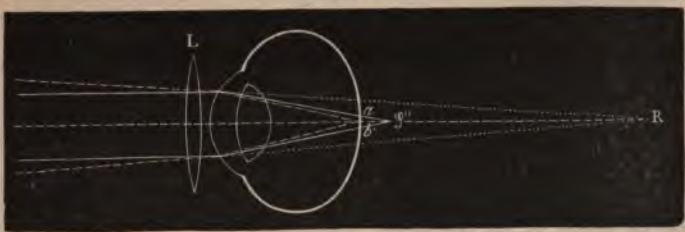
When the retina is found *in front* of the focus of the dioptric system, parallel rays are united *behind* it (*Fig.* 13) and make a diffused image a, b.

In order to be united on the retina the rays must be already more or less *convergent* before reaching the eye, as is indi-

cated by the broken lines in Fig. 13. Now, there do not exist any converging rays in nature. Those which come from objects *near at hand* are *divergent;* those coming from *infinity* are *parallel;* in order to be *convergent* it would be necessary for them to come from *beyond infinity*, so to speak. The name of *hypermetropia* has been given to that condition of the eye in which it is adapted for a point situated *beyond the normal distance* to which the emmetropic eye is adapted.

The *punctum remotum* to which the hypermetropic eye is adapted in a state of rest is not to to be found *in front* of the eye. It corresponds to the point of intersection of the convergent rays which the eye requires in order to see distinctly. By prolonging

FIG. 13.



these rays we find this point of intersection (*R* Fig. 13) *behind* the eye.

The punctum remotum of the hypermetropic eye, instead of being the point from which the rays of light emanate, is, on the contrary, the point to which they should converge in order to be united on the retina, because its *refracting power is too feeble relative to its length* (see Fig. 13). In order to make it emmetropic its refracting power must be *increased* by adding to it a *convex* lens. The number of the lens which adapts the hypermetropic eye to vision at a distance with parallel rays, indicates at the same time by how many dioptries the hypermetropic eye is more feeble than the emmetropic eye, and thus gives the measure of the hypermetropia. If the convex lens has 6 dioptries, the refracting power of the eye is feebler by 6 dioptries than the emmetropic eye, and consequently the hypermetropia is expressed by 6 D.

But the correcting lens shows us yet another thing: if the hypermetropic eye, which has need of convergent luminous rays, sees distinctly at infinity, through a convex lens, it follows that the convergence communicated, by the lens, to the parallel rays is exactly that of which the eye has need. Now, the lens causes parallel rays to converge toward its *focus*, and the rays which the hypermetropic eye unites on its retina should converge toward its *punctum remotum*.

The punctum remotum of the eye and the focus of the correcting glass should, therefore, coincide, and the focal distance of the convex lens, placed just in front of the eye, is therefore equal to the distance which separates the eye from its punctum remotum.

The focal distance of the correcting lens being, in our example, $\frac{100}{6} = 16$ cm., the punctum remotum is situated at 16 cm. *behind* the eye. If we place the correcting glass at a certain distance in front of the eye, say at 2 centimeters, it should have a greater focal distance. In this case, the punctum remotum being situated 16 centimeters behind the cornea, and the glass being 2 centimeters in front of it, the focal distance should be $16 + 2 = 18$ centimeters, and its power, not 6, but $5\frac{1}{2}$ dioptries ($\frac{100}{18} = 5.5$) in order that its focus coincide with the punctum remotum. With respect to the eye, the action of the convex lens is the stronger the further it is removed from it. It is, therefore, important to take into account the distance at which the correcting lens is placed from the eye.

In practice we cannot always tell whether the individual brings his accommodation into play. This, however feeble it may be, diminishes the manifest degree of the hypermetropia; it is for this reason that we should take as the expression of the hypermetropia, the *strongest convex lens which adapts the eye to infinity;* that is to any distance beyond 5 meters.

It is on this account that young hypermetropes who have yet possession of the full power of their ciliary muscles, and those whose hypermetropia is not very great, see perfectly well at a

distance, and even quite close at hand, without the intervention of convex glasses.

Causes of Hypermetropia.—Hypermetropia, which, as we have seen, consists in this, that the principal focus of the dioptric media is situated *behind* the retina, can be produced by different causes.

1st. The dioptric system of the hypermetropic eye may be the same as that of the emmetropic eye, but the *axis* of the eye may be too short, as represented in Fig. 13. I have given to this form the name *axial hypermetropia* (hypermetropie axile), and the sign H^a indicates at once the nature of the ametropia and its cause.

2d. The length of the hypermetropic eye may be the same as that of the emmetropic eye, but the *refracting power* may be *too feeble*, either on account of a diminution of the convexity of the cornea or of the surfaces of the lens, or on account of the absence of the lens, constituting hypermetropia from insufficient curvature (hypermetropie de courbure), H^c.

3d. It may be that the *index of refraction* of the aqueous humor or the lens is diminished, constituting H^i.

The most frequent variety of hypermetropia is the *axial* form, that is to say, hypermetropia produced by an arrest of development of the eye in its totality, or in its antero-posterior diameter. These eyes are distinguished by their smallness and mobility. It is on this account that, when the eye is turned as much as possible toward the nose, and the lids are widely separated, we are able to see not only the equatorial portion strongly curved, but to see that the back part of the globe slopes quite suddenly toward the posterior pole.

The second form of hypermetropia—*hypermetropia from insufficient curvature*—is much rarer; the cornea of the hypermetropic eye being generally more convex than that of the myopic eye.

There is, however, a hypermetropia produced by a depression

in the cornea as a consequence of keratitis. H^c also follows, sometimes, as a result of the flattening of the cornea from the increase of intra-ocular tension, and from the flattening of the lens, in paralysis of the ciliary muscle.

It is hardly necessary for me to call your attention to the hypermetropia caused by the absence of the lens; you have all seen cases of luxation of the lens, and you see every day those who have been operated on for cataract armed with strong convex lenses, which correct the high degree of hypermetropia which follows extraction of the crystalline lens. Finally, the hypermetropia which is developed in advanced age, first demonstrated by Donders, should, perhaps, be referred to a flatness of the lens as a whole in consequence of senile degeneration. It is an example of H^1.

MYOPIA.

Returning now to the experiment with the convex lens and screen, if, instead of advancing the screen on which the image of the flame is received, we remove it further away, we obtain again an indistinct image (b' a', Fig. 12). This is caused by the divergence of the rays after their union at the focus, and this condition corresponds to that of *myopia.* We define myopia, therefore, as follows:—

Myopia is that condition of the eye in which the retina is situated behind the focus of its dioptric apparatus; and, expressed in a general manner, we may say that *the dioptric system of the myopic eye is too strong, relative to its length.*

In order that the rays coming from the flame may be brought to a focus on the screen, it will be necessary either to render them more convergent by bringing the flame nearer (at R, Fig. 12), or, the flame remaining at infinity, to diminish the refracting power of the lens.

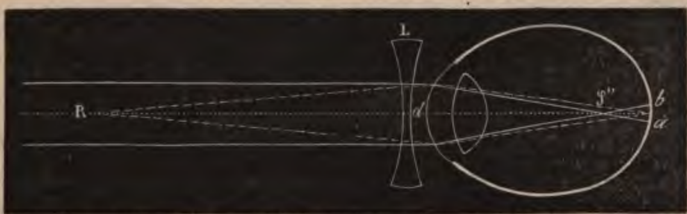
So, in order to adapt the myopic eye to infinity, that is to say, to render it emmetropic, we must *diminish* its refracting power.

This can be accomplished by *concave* glasses; and the number of the concave glass which allows the eye to see at infinity represents the *degree of the myopia,* because it shows by how many dioptries the refracting apparatus of the eye is stronger than that of the emmetropic eye.

In taking account of the action of the correcting concave lens we will find again the same coincidence of its focus with the *punctum remotum* of the myopic eye that we found in the case of hypermetropia.

The *myopic* eye in a state of rest is adapted for its *punctum remotum* situated at a certain distance in front of it; in other words, in order to see distinctly, it must have rays diverging from its *punctum remotum.* Now, the action of a concave lens is to render parallel rays divergent, as if they came from its focus.

FIG. 14.



When a concave lens adapts the myopic eye to vision at a distance, it shows that that lens gives to parallel rays a divergence, as if they came from the *punctum remotum* of that eye. On this account, the focus of the correcting lens and the *punctum remotum*, *R*, of the myopic eye, coincide. If the eye requires a concave lens, No. 6, placed close to the cornea ($d = 0$, Fig. 14) its *punctum remotum*, *R*, is situated at 16 centimeters in front of it, because the focal distance of this lens is equal to 16 centimeters.

If we place the correcting lens at 2 centimeters from the cornea ($d = 2$ centimeters), the focal distance LR should be 2 centimeters less, that is, 14 centimeters, and the lens will then be not 6, but 7, dioptries ($\frac{100}{14} = 7$ D).

You see that it is by no means a matter of indifference as to where you place the correcting lens; the further the concave lens is from the eye the stronger it must be, and *vice versa*. Those among you who use concave glasses have doubtless frequently observed that the closer they are approached to the eyes the stronger is their action.

Since it is only necessary to measure the distance between the *punctum remotum* and the eye in order to know the degree of the myopia, we can determine this degree even without the intervention of a lens. It is sufficient to cause the individual to read small print at the greatest distance he is able. In this manner we find the punctum remotum; and the distance which separates this from the eye is the focal distance of the lens which gives the degree of the myopia.

Suppose a myope to read without any effort of the accommodation at a distance of 9 centimeters. His myopia will be equal to 11 D, because 9 centimeters represent the focal distance of 11 D ($\frac{100}{9} = 11$).

In the determination of myopia we should again take account of the accommodation; if this is not absolutely suspended, the myopia will appear much higher than it is in reality, on account of the increase in the refracting power of the eye. It is for this reason that we should always choose the *feeblest concave lens* which gives the best vision at a distance. In the direct determination we should take as the focal distance of the lens for correcting the myopia the *greatest* distance at which small print is read.

Causes of Myopia.—Myopia, like hypermetropia, has different causes for its production.

1st. The eye may be *too long* for a dioptric system as strong as that of an emmetropic eye; *axial myopia* (myopie axile), M^a.

2d. The dioptric system may be too strong, while the length of the eye remains emmetropic; *myopia from excessive curvature* (myopie de courbure), M^c.

3d. The index of refraction of the dioptric system may be increased, M^i.

I. AXIAL MYOPIA, M^a.

Myopia from an excessive length of the eye is by far the most frequent form. You doubtless call to mind the protruding eyes of certain myopes, even when the myopia was of slight degree.

As we said, in the second lecture, hypertrophy of the globe (if we can call it such) can attain to such a degree that the eye is restricted in its movements. The lengthening is more pronounced in the direction of the optic axis by the formation of a *staphyloma posticum*, an ectasia in the region of the macula lutea which is so frequently a cause of myopia.

II. MYOPIA FROM EXCESSIVE CURVATURE, M^c.

Myopia from excess of curvature is much rarer than the axial form, the cornea of the myope not differing generally from that of the emmetrope, having, indeed, frequently a longer radius of curvature. Examples of this kind of myopia are *conical and staphylomatous corneæ.*

We sometimes see an apparent myopia due to an excess of curvature of the lens, caused by a spasm of the ciliary muscle. In this case the myopia disappears under the influence of atropine.

III. MYOPIA FROM AN INCREASE OF THE INDEX OF REFRACTION, M^i.

Sometimes in the course of the development of a cataract we find a myopia which did not exist previously. It is due, without doubt, in such cases, to an increase of the index of refraction of the lens.

We have seen, gentlemen, that the great majority of cases of ametropia is due to differences in the *length* of the eye, the dioptric apparatus remaining the same as that of the *emmetropic* eye.

From this it will appear that the expression "anomalies of refraction," by which ametropia is usually designated, is not exact. Indeed, it is not the refraction, but the length of the eye which is abnormal in these cases. If we designate the axial ametropias by the name "anomalies of refraction," we should always add mentally, *in relation to their length.*

LECTURE VII.

ASTIGMATISM.

Gentlemen:—In the different forms of refraction of the eye which we have hitherto studied it has always been supposed that its refracting surfaces were *spherical*, a condition in which, since all the meridians have the same curvature and refract equally, the rays are brought to a focus in one and the same point.

We have no need to speak of the eye as not being a perfect instrument in the strict sense of the word. We seldom ever find an eye which fulfills, mathematically, the conditions of a perfect instrument. The departure from a spherical form is, however, in the majority of cases, so small that we can very properly neglect it, in practice.

But frequently this inequality in the curvature of the different meridians of the refracting surfaces of the eye is so great as to influence, in no inconsiderable degree, the acuteness of vision, and it then constitutes a peculiar form of anomaly of refraction which is known as *astigmatism*.

Astigmatism consists in an irregularity of the curvature of the dioptric surfaces of the eye, which deviate in various degrees from the normal spherical form. The refraction of an astigmatic eye is, therefore, not the same in its different meridians. It is strongest in the meridians with the strongest curvatures, and most feeble in those where the curvature is least.

We can imitate, artificially, this anomaly by means of a cylindrical lens. A cylindrical lens is one formed by a section of a cylinder of glass made parallel to its axis, or by two of these sections symmetrically associated.

A cut made across a convex or concave cylindrical glass perpendicular to its axis presents, therefore, the form of Fig. 15 or Fig. 16, while a cut parallel to the axis has simply the form of Fig. 17, thicker or thinner, according as it is made nearer the border or middle line of the cylinder. The rays of light which pass through the cylinder in a plane perpendicular to its axis are brought to a focus in the same manner as they are by all convex lenses, while those which pass in a plane parallel to the axis undergo no more deviation than if they had passed through a glass with plane parallel surfaces.

FIG. 15. FIG. 16. FIG. 17.

The same is true of *concave* cylindrical lenses, which disperse only the rays which pass through them perpendicular to their axes.

Take, for example, the convex cylindrical lens No. 5 and combine with it a spherical convex No. 50, the refracting power of which is nearly the same as that of the dioptric system of the eye, since it unites parallel rays 20 mm. behind it.

Rays coming from a luminous point at a great distance and passing through this combination in a plane parallel to the axis of the cylinder are affected only by the spherical glass, the cylinder exerting no influence on it in that direction, and they are brought to a focus in a point 20 mm. behind the combination.

The rays, on the contrary, which pass through the system in a plane perpendicular to the axis of the cylinder will be affected by both the spherical No. 50 and the cylindrical No. 5, making,

together, 55 D; they will be brought to a focus, therefore, at $\frac{1000}{55} = 18$ mm. behind the lens, consequently 2 mm. in front of the point of union of the rays passing through the plane of the axis, and at a place where these latter form an image of diffusion. On the contrary, at the focus of the rays which have passed parallel to the axis of the cylinder, the rays of the plane perpendicular to the axis form an image of diffusion by diverging after their union.

In the space comprised between the foci of the two PRINCIPAL MERIDIANS (that is to say, those meridians with the maximum and minimum of curvature) are to be found the foci and the images of diffusion of the rays which pass through the system in the intermediate meridians.

From this it results that such a system can never furnish a distinct image of a luminous point. At whatever point we place the screen to receive the image, there will always be only one part of the rays which comes to a focus there; the other makes an image of diffusion. If we place a cylindrical lens like the one we have mentioned in such a position that its axis is horizontal, and if the screen is 18 mm. behind the combination, then the vertical meridian only is adapted for the distance of the luminous point, and the image will be a horizontal line, because all the rays which have passed through the vertical meridian are united on the screen, while the others, especially those which pass through the horizontal meridian, form images of diffusion.

By removing the screen the line enlarges at the same time that it gets shorter, and the image becomes an ellipse with a long horizontal axis. If we continue to remove it, the long axis of the ellipse becomes shorter while the short axis becomes longer; the image of diffusion assumes a circular form, to again become an ellipse, with its long axis vertical; finally this ellipse grows narrower and narrower until it becomes, at 20 mm. behind the combination, a *simple vertical line.* In this last position the focus of the *horizontal* meridian is found on the screen.

The image of a luminous point made by a dioptric system the

different meridians of which have different refracting powers, is, therefore, never a point, but a line, or an image of diffusion, elliptical or round in shape.

This condition may occur in the eye. Suppose an eye, whose vertical corneal meridian has a curvature stronger than the horizontal; this eye looking at a point will always see a horizontal or vertical line, or a diffuse luminous spot, but never a point. From this fact comes the name *astigmatism* (from *a*, privative, and στίζω, στίγμα, a point,) which has been given to this anomaly of refraction.

When, as in the example which we have taken, the curvature remains the same throughout the whole extent of the same meridian, the astigmatism is called *regular.*

If, on the contrary, not only the different meridians have different radii of curvature, but the curvature of the same meridian varies in its different parts, it is called *irregular* astigmatism.

We would therefore define *regular astigmatism to be that condition in which the refraction is different in the different meridians of the eye.* It has its seat nearly always in the cornea, which, instead of being spherical, has the form of a sphere compressed from two opposite sides.

The *principal meridians* (most frequently the horizontal and vertical) are, in the great majority of cases, *perpendicular* to one another, and in that case the vertical meridian is nearly always the more strongly curved. The exceptions to this, however, are not rare. The principal meridians are frequently inclined, and sometimes we see the feebler curvature corresponding to the vertical.

Returning now to our two combined lenses, let us apply their principles to the eye, in order to bring clearly before our minds the symptoms which are manifest in the astigmatic eye, as well as the manner of determining and correcting that anomaly of refraction.

Suppose the eye to have a length of 20 mm., and that its dioptric system is represented by the combination of a + 50 spherical lens, and a + 5 cylindrical lens axis horizontal. The horizontal meridian of the eye will then be emmetropic, since the cylinder exercises no influence on the direction of the rays in the plane of its axis; the spherical lens alone refracts the light, and brings parallel rays to a focus at 20 mm. behind it, that is to say, on the retina.

In the vertical meridian, on the other hand, the refraction of the eye is 5 D stronger than that of the emmetropic eye. The eye has, therefore, a myopia of 5 D in that meridian. Rays coming from infinity are united *in front* of the retina, and in order to see clearly, the object must be brought up to $\frac{100}{5} = 20$ cm. An eye having this irregularity of refraction cannot see horizontal lines distinctly when they are placed beyond 20 cm., the vertical meridian being adapted only for objects nearer than 20 cm. A line can be considered as composed of an infinite number of points placed close to one another; each of these points will form an image of diffusion in the vertical axis, and all the points together will form a broad and ill-defined line.

In order to see the horizontal line clearly, it must be brought up to 20 centimeters. Then the images of diffusion of the points which make up the line are horizontal, that is, in the direction of the line, consequently they overlap each other, while the rays which come from the vertical direction are accurately focused on the retina. The line, therefore, does not appear broader, but only slightly elongated, on account of the horizontal diffusion at its two extremities.

The contrary takes place for a vertical line. It will be seen clearly at a distance because the horizontal meridian, perpendicular to its direction, is adapted to its distance, while it will be confused on nearer approximation because it forms images of diffusion in the horizontal axis. An eye of this kind will, therefore, never see

horizontal and vertical lines distinctly when they lie in the same plane. If you place a black cross made on white paper before it, it will see either the one or the other line distinctly, according as the paper is approximated to or removed from it, or as its accommodation adapts the one or the other of its principal meridians to the distance at which the paper is placed, but it will never see the cross, as a whole, clearly and distinctly.

It was this observation, among others, which led to the discovery of astigmatism, and which furnished a means for its determination.

The astigmatic eye never has a perfect acuteness of vision, and, indeed, often presents a very high degree of amblyopia. When we have found a spherical glass which gives relatively the best visual acuteness, and when we have reason to suspect the existence of astigmatism—the indications of which we shall see further on—we place before the patient a figure composed of black rays spread out like a fan on a white ground (SNELLEN, GREEN). It should be about 5 meters (16 feet) removed from the eye. While one eye is covered, and the other is armed with the lens giving the best vision (if a glass be required), we ask if all the lines appear equally sharp, black and broad. If the answer is in the negative we then ask which ray appears clearest, and which most indistinct. These rays will correspond to the two principal meridians, and are most generally perpendicular to each other.

Since one of the two lines appears clear and distinct, the meridian which is perpendicular to it is adapted to the distance of that line, whether the patient sees with or without the aid of glasses. It only remains for us, therefore, to correct the ametropia of the other meridian. This is effected by means of a cylindrical glass, the axis of which is perpendicular to the meridian to be corrected, and which must be added to the correcting spherical lens.

The cylindrical lens will be convex or concave according as the meridian to be corrected is hypermetropic or myopic; and the

cylinder which, with the spherical lens, gives the best vision, is the correcting cylinder required. Its number gives the degree of astigmatism, that is, the difference in the refraction of the meridians of least and greatest curvature.

To verify the exactness of our examination the patient is caused to look at the fan, and if the astigmatism is corrected all the lines will appear of the same sharpness.

Donders has given the name of *simple astigmatism* to that form in which one of the principal meridians is emmetropic, and makes a subdivision into *simple hypermetropic* and *simple myopic* astigmatism, according as the ametropic meridian is hypermetropic or myopic.

The astigmatism is *compound* when both the principal meridians are ametropic but of the same character. Thus we see frequently an eye myopic in all its meridians have its myopia stronger in the vertical than in the horizontal meridian. An analogous condition is frequently found in the hypermetropic eye. In these cases we say, for instance, there is M. 5 D. + As. M. 1 D. in the vertical meridian, which is equivalent to saying that the horizontal meridian presents a M. of 5 D., the vertical a surplus M. of 1 D.; a total of 6 D. Finally, the astigmatism is *mixed* when one of the principal meridians is hypermetropic and the other myopic.

All these forms of astigmatism are of frequent occurrence; the *mixed* form, however, is less common than the others.

Simple astigmatism is corrected by a simple cylindrical glass with the axis perpendicular to the ametropic meridian; *compound astigmatism* by glasses which are spherical on one side and cylindrical on the other; and *mixed astigmatism* by bi-cylindrical glasses whose axes are perpendicular to each other.

The first studies in astigmatism were made by Thomas Young*

*"Philosophical Transactions," 1793, vol. 83, p. 169, and "Miscellaneous Works" of the late Thomas Young, edited by Peacock, London, 1855, vol. 7, p. 26.

(1793), who, himself affected with a very considerable astigmatism, analyzed and corrected it in a manner as ingenious as it was exact.

It is very curious that this first recorded case of astigmatism had, contrary to the rule, its seat not in the cornea, but in the lens. Airy * determined and described the compound myopic astigmatism with which he was affected. He wore a concave spherical combined with a concave cylindrical glass.

Later (1845) Sturm † established the mathematical theory of astigmatism, and Stokes ‡ invented, for its determination, his well-known instrument composed of two cylindrical glasses, movable one on the other in such a manner as to produce a cylindrical lens of a variable strength.

One of the most curious instances, from a historical point of view, is that of the curate Schnyder, of Menzberg, Switzerland, who had observed that he could not clearly distinguish horizontal and vertical wires at the same distance, and who corrected the infirmity by means of a convex cylindrical lens. § In 1852 Goullier, professor in the School of Application of Metz, sent to the Academy of Sciences a sealed communication, which was opened on the 7th of August, 1865, and contained the explanation of astigmatism and the method of its correction by means of cylindrical lenses.

Since the invention of the ophthalmoscope, and the remarkable works of Donders, Javal, Knapp and others, astigmatism has become as well known and understood as hypermetropia and myopia.

It was by means of ophthalmometric measurements that the

* "Transactions of Cambridge Philosophical Society," vol. ii, p. 267, 1827.

† Comp. rend. de l'Acad. des. Scien. de Paris, t. 20, pp. 554, 761, 1238 et Pogg. Ann. t. 65, p. 116.

‡ "Report of the British Association for the Advancement of Science, for 1849," p. 10.

§ Comp. rend. de la Société Guisse pour l'Avancement des Sciences Notarelles et *Ann. Doc.* t. xxi, p. 222, 1849.

cornea was proved to be the principal seat of astigmatism, and the School of Utrecht has been mainly instrumental in introducing into practice the methods which are employed for its determination and correction.

IRREGULAR ASTIGMATISM.

While regular astigmatism, in spite of the difference in curvature of the various meridians of the refracting surfaces, presents a regular curvature in each meridian taken singly, *irregular astigmatism consists in a difference of curvature in the different parts of the same meridian.* This anomaly of refraction may have its seat in either the cornea or lens.

In the case of the cornea the astigmatism is most frequently produced by inflammatory processes and ulcers which have left its surface of an irregular form. Flat, or even excavated parts, are often found by the side of partial ectasies, and frequently each small part of the cornea has a curvature different from that adjacent to it.

The individual is sometimes more inconvenienced by such an irregularity of the corneal curvature than by leucomata, because, the light undergoing a very irregular refraction at the first refracting surface of the eye, the retinal image becomes in the highest degree distorted. No object is seen distinctly, straight lines sometimes appearing enlarged and blurred at certain parts, or showing inflections and irregularities of all kinds. It is evident that such an anomaly of refraction cannot be corrected by either cylindrical or any other kind of glasses, because it would be impossible to give to glasses a form similar to that of the irregular cornea.

In such cases we can somewhat improve vision by a means first proposed by Donders. Since the amblyopia here is due to the fact that the different parts of the cornea have different curvatures and the rays of light passing through them are not united in the same place, only that part of the cornea can be utilized for

vision which has an approximately spherical surface, by eliminating the others.

This end is attained by means of a diaphragm having a hole from 1 to 2 mm. in diameter, which is held close to the eye. The patient soon finds the position in which the stenopaïc hole gives the best vision, and we sometimes find the advantage gained by this method by no means inconsiderable. It is true that the illumination is diminished on account of the exclusion of a great quantity of the light which, without the diaphragm, would enter the eye; but, on the other hand, the distinctness of the object is much increased, because the luminous rays which have passed through the hole and the corresponding part of the cornea are united to form a single clear image on the retina.

A form of irregular astigmatism more important and more common than that met with in the cornea is found in the *lens*, and up to the present time there are only two individuals who are known to have been exempt from it. Of these cases we shall speak further on. This irregular astigmatism is produced by the structure of the lens itself. You will remember that the lens is composed of many sectors, whose lines of separation form a kind of star, frequently visible by means of the oblique illumination, and especially pronounced in senile cataract.

Now, the different sectors of the lens have not exactly the same curvature, and consequently the light which passes through them is not brought to the same focus; each sector forming a separate image. Under ordinary circumstances, and in cases where the irregularity is not excessively developed, the retinal images corresponding to the different sectors overlap each other, and we see the object single, though less distinctly than if the lens had regular surfaces.

In other cases the numerous images furnished by the lens produce a *polyopia monocularis*, that is to say, the eye, instead of seeing a single image of the object fixed, sees many. This phenomenon has been accurately observed and described by Vulpian

and Donders. The classical description which they have given of it is to be found in the memoirs of the *Society of Biology*, for the year 1861, t. iii, p. 335 (Vulpian), and in "The Anomalies of Accommodation and Refraction of the Eye," pp. 451–545, 1864 (Donders).

This polyopia becomes especially apparent when the eye is not adapted to the distance of the object that is fixed, because then the images corresponding to the different sectors are separated further from each other than when it is accurately accommodated.

Vulpian observed his polyopia principally when looking at the crescent of the moon. Other observers, as La Hire, Th. Young and Donders, have generally used a luminous point brought quite close to the eye. We can, according to Donders, easily produce a polyopia monocularis by means of a small globule of mercury placed on a piece of *black velvet*. The globule acts as a very strong convex mirror, from which can be reflected a small image of any luminous source, such as the sun, lamp, etc.; this small image acting as a luminous focus from which rays diverge. By bringing the globule to within a few millimeters of the eye, instead of a single round image of diffusion we see numerous images, which, to a greater or less extent, overlap each other. These are the *entoptic* images furnished by the different sectors of the lens.

It is this same irregularity in the structure of the lens which causes a luminous point to appear to us as if radiated. Indeed, is it not surprising that the luminous heavenly bodies, in spite of their spherical shape, make on the human eye, not the impression of round, luminous points, but the impression of bodies with rays? From this circumstance we have the extension of the word *stellate* to all bodies presenting a similar appearance. This fact is a proof that human eyes have for all time presented the same irregular astigmatism. There are only two examples known of men having possession of their crystalline lenses that were exceptions to this rule. One was a tailor, named Schoen, of whom Alexander von Humboldt reported that the stars appeared to him as points clearly

rounded. The other is in the person of one of my own pupils. Mr. D. has never been able to understand why the stars are compared to figures with radiating lines. They appear to him as luminous points without any rays. The lenses of Schoen and Mr. D. must have been constructed with great exactness, or the irregularities of the anterior surface of the lens must have been neutralized by the irregularities of an opposite kind on the posterior surface.

We are able, however, to put ourselves in conditions analogous to these fortunate men by looking at the stars through a diaphragm perforated with a small hole. In this way we deprive the stars of their rays, and reduce them to small, luminous points, because their images are formed on our retinæ by only one of the sectors, or by a part of the lens which has approximately the same curvature throughout its whole extent; only, the luminous points appear less brilliant to us than they must have appeared to Schoen or do to Mr. D., since they saw them through the whole extent of their pupils, while we see them only through an excessively small pupil, the stenopaïc hole in our diaphragm.

The irregular astigmatism of the lens does not influence vision very much under ordinary conditions, but it can become a very serious obstacle in astronomical observations. Irregular astigmatism renders it impossible to determine the exact point of contact of two bodies.

Thus, if you close one eye and fix, with the other, the ends of the thumb and index finger and bring them together gradually, you will observe that before contact there will be formed between them a kind of drop, and that they appear to run into one another, as it were.

This phenomenon is the result of the irregularity of the lens which we have just been studying, and which prevents the formation of images, absolutely clear, on our retinæ, and, consequently, renders impossible the exact determination of the moment when the two fingers touch each other.

This fact attracted considerable attention in connection with the observation of the transit of Venus across the face of the sun. It was a question as to how it would be possible to tell the precise moment when the edge of the disc of Venus came in contact with that of the sun, and the moment when the two separated.

It was Giraud-Teulon who, giving the explanation of the phenomenon, indicated the method to obviate it.* We have only to arm ourselves with a stenopaïc hole, in order to make the contours clear, and the difficulties are removed. If we place before the eye a card perforated with a hole 0.5 millimeter in diameter, we will see that the drop is not formed between the fingers.

Irregular astigmatism changes with the alterations in the structure of the lens; and it is especially observed during the formation of cataract. You frequently hear aged persons say that since a certain time the stars present more and longer rays, that such and such a star seems to have satellites, or that the moon appears multiple. In such cases you will nearly always find opacities of the lens on examination with the oblique light.

After a successful operation for cataract, irregular astigmatism disappears, but only to give place, in many cases, to a regular astigmatism coming from a change in the form of the cornea, due to the cicatrization of the wound. This astigmatism can, however, be corrected in the majority of cases by cylindrical glasses, while, for irregular astigmatism there is, aside from extraction of the lens, no remedy but the stenopaïc hole.

* Ann. d'occul, t. lxviii, p. 39.

LECTURE VIII.

THE CAUSES OF AMETROPIA.

GENTLEMEN:—As many of you have expressed a desire that I should consider yet further the causes of ametropia, I take this opportunity to give a general outline of the various causes which may render an eye ametropic, and of the manner in which I would have the matter considered.

You will remember that in all questions pertaining to the optics of the eye we take, as a standard, the *emmetropic* or normal eye.

The *emmetropic* eye is one in which the retina is at the focus of its dioptric system. Its usual length is 23 millimeters; but this is by no means a characteristic of emmetropia, which is in reality only a *relation* between the length and the refracting power of the eye. We can easily conceive of an eye shorter than 23 millimeters but possessed of a more than usually strong refracting power; or of one longer with a dioptric system of less power. In both of these cases the retina may be found in the focus of the dioptric system, and the eye, consequently, be emmetropic.

When the retina is not found at the focus of the dioptric system the eye is *ametropic*, and it may appear under two forms:—

a. The retina may be *in front of* the focus (hypermetropia).

b. The retina may be *behind* the focus (myopia).

These anomalous conditions can be produced by a variety of causes.

Causes of Hypermetropia.—In hypermetropia, as we have said, parallel rays are united behind the retina. The hypermetropic eye, therefore, possesses a refracting power *too weak in relation to its length.*

This may be due to the fact that, while possessing a dioptric system equal in its refracting power to the emmetropic eye, it is shorter than normal. We call this form axial hypermetropia, H^a.

On the other hand, an eye which has the same length as an emmetropic eye will be hypermetropic if its refracting power is too weak to unite parallel rays on the retina. This is refractive hypermetropia, H^r.

The dioptric system of the human eye being more constant than its length, axial ametropia is more frequent than the refractive form, although a difference in the radius of curvature of the cornea has a much greater influence on the refraction than a similar difference in the length of the ocular axis.

The animals which we have examined as regards their refraction by means of the ophthalmoscope, such as frogs, rabbits, cats, dogs, etc., are all hypermetropic, sometimes as much as three or four dioptries (about No. 10 of the old system). This fact is the more surprising as their ciliary muscles are not well developed, and it is highly probable, therefore, that they cannot accommodate accurately for objects close at hand.

Infants are, in the majority of cases, hypermetropic, even many of those who afterward become emmetropic and myopic. The ophthalmometric measurements of Donders and others have proved that the cornea is not generally less convex than that of emmetropes and myopes. We are, therefore, warranted in considering hypermetropia, in the majority of cases, as an arrest of development of the globe of the eye.

We class also as axial hypermetropia the hypermetropia which we find at the peripheral parts of the retina, even in those eyes which, in the direction of their axes passing through the macula, are emmetropic or myopic. These parts are closer to the cornea than those situated in the line of the principal axis of the eye. Finally, we have, as striking examples of axial hypermetropia, that which is caused by tumors under the retina, detachment of the retina and optic neuritis.

Refractive hypermetropia may be due to an insufficient convexity of the refracting surfaces, cornea and lens (hypermetropia from an anomaly of curvature, H^c), or to a diminution of the index of refraction of the aqueous humor or crystalline lens, or to an increase in the refraction of the vitreous humor (hypermetropia from insufficiency of the index of refraction, H^i).

H^c has been demonstrated by Donders, Mauthner and others, in cases of flattening of the cornea in kerato-malacia, and ulcerations of the cornea resulting in a lessened curvature. It is found in advanced age (beyond 70 in emmetropia), most probably in consequence of flattening of the lens. We may also class under this head cases of simple hypermetropic astigmatism, where one meridian is hypermetropic and the other emmetropic.

H^i is represented in aphakia and dislocation of the lens. The hypermetropia of advanced age is also, probably, due, in part, to the lessened index of refraction of the lens as a whole, caused by the corticalis becoming more nearly of the same density as the nucleus.

In certain exhausting diseases, such as diabetes, the index of refraction of the lens may undergo a modification. The hypermetropia often found in the glaucomatous condition is due to a lessening of the curvature of the cornea, from increased pressure from within, which causes the eyeball to approach, in form, more nearly to a perfect sphere. It is H^c.

Causes of Myopia.—Myopia, according to the definition we have given, is due to an excess in the length of the eye in relation to its refracting power. In such a condition, parallel rays are brought to a focus in front of the retina.

We here, likewise, distinguish two forms (*a*), an *axial myopia*, M^a, in which, the dioptric system being the same as that of the emmetropic eye, the axis is longer than that of the emmetropic eye (23 mm.), and (*b*) a *refractive myopia*, M^r, where the length of the eye is normal, but its refractive power too great.

Axial myopia, M^a, may be congenital, and due to an exaggerated

development of the eye, or it may be acquired, and caused by diseases which bring about an elongation of the globe in its antero-posterior diameter, such as choroiditis, staphyloma posticum, etc. These two forms are very frequent.

You will find, in nearly all treatises on ophthalmology, myopia described as a serious disease which is liable to bring about choroiditis, alterations at the macula, staphyloma posticum, and even choroidal hemorrhages, and detachment of the retina.

Properly speaking, myopia is not a disease, it is only a symptom indicative of a discrepancy between the length of the eye and the focal distance of its dioptric apparatus. It is not the myopia which produces the choroiditis and staphyloma posticum, it is the choroiditis which brings about the staphyloma posticum, which in its turn removes the retina beyond the focus of the dioptric system.

Thus the defenders of the theory generally accepted in regard to myopia will be much embarrassed when they are shown a hypermetrope with a crescent at the edge of the optic disc, a papilla obliquely placed, and even with a staphyloma; in a word, with all the conditions at the fundus of the eye which are theoretically characteristic of myopia. According to our manner of looking at the matter there is no difficulty in explaining this condition of affairs. In fact, no eye is safe from an attack of choroiditis posterior; the emmetropic and hypermetropic eye can be affected as well as the myopic, because it is not the state of the refraction that is the cause of it. At the beginning the morbid process is not sufficiently intense to bring about all the unfortunate consequences we have mentioned, the sclerotic does not give way, there is no staphyloma, and if a staphyloma does form in a strongly hypermetropic eye, it will lessen the hypermetropia and render it emmetropic, and it is not always the case that the staphyloma is so extensive as to change a hypermetropia into a myopia.

In this way we can account for the fact that the same work, the same fatigue of the eye, undue approximation of objects, work

under insufficient illumination, the use of concave glasses, etc., do not entail myopia upon the millions of individuals who are daily exposed to these injurious influences, while in others myopia is developed even with a moderate use of the eyes, and progresses in spite of a cessation of the work. These facts cannot be explained so long as myopia is looked upon as a disease *per se.* It should be looked upon in these cases as a symptom of a choroiditis posterior, for which we must endeavor to find a cause, and this is often found in some general morbid condition. It is evident that myopia will be developed more rapidly, and attain to a higher degree, in eyes that are already relatively long, emmetropes and slight myopes, such as we frequently find in connection with an undue development of the orbit and skull in the antero-posterior axis. Thus race becomes a probable factor in the development of myopia.

M^r—myopia from excess of refraction—can be divided into myopia from excess of curvature, M^c, and myopia from excess of index of refraction, M^i.

An increase in the curvature of the cornea is not very frequent, but more frequent, however, than is commonly supposed. It is very pronounced in conical cornea and anterior staphyloma. Thus the anterior and posterior staphyloma act together to produce M; the first principally by increasing the curvature of the cornea, the last by increasing the length of the eye.

The myopia which an emmetrope produces when he accommodates for near objects is an example of M^c. In luxation of the lens, the curvature of its surfaces is increased, since they are removed from the action of the zone of Zinn, which keeps them flattened. Under the same head must be ranged the myopia which Jäger has found in new-born infants, and which he attributed to a disproportion between the development of the lens and that of the ciliary muscle.

As M^i we must class those cases where the index of refraction of the lens has been increased by age, a condition which, in this case, counterbalances the flattening of the cornea. This form of

myopia is also seen at the beginning of cataract.* We are not aware that a diminution of the index of refraction of the vitreous humor has ever been observed, but such a condition would cause a myopia of this kind.

Diagnosis of the Causes of Ametropia.—Is it possible to discover in the living eye, in any given case, the cause of its ametropia? It is assuredly not difficult to determine whether an eye is emmetropic, hypermetropic or myopic, and even the degree of its ametropia, but it is a much more difficult matter to discover the cause of the ametropia when found to exist.

In order to find, for example, if an eye with a given myopia is longer than an emmetropic eye, or if, its length being normal, its refracting surfaces are too convex, or finally, if it is its index of refraction which has increased, it is necessary to determine the length, curvature and index of refraction of that eye, or, at least, two of the three factors from which we can deduce the other. Is such a determination possible during life? Yes, it is possible, but not always easy.

Physiological optics has the means of measuring and calculating with very great exactness all the data pertaining to the refraction of the eye, but they are not always applicable in ordinary practice.

1. As regards the length of the eye, we can judge of it approximately in the very easy and simple manner which we have already mentioned. Open the lids widely and draw them somewhat outward, and cause the patient to look as far as possible to the opposite side. We are in this way enabled to judge, both by sight and touch, of the length of the eye and the form of its posterior portion. This simple examination, rough though it may seem, will give very important indication to one who will practice

*The "second sight" of old people, of which almost every community furnishes an instance, is due to the development of M, either from an increase in the index of refraction of the lens or a lengthening of the antero-posterior axis. There is, in such cases, no rejuvenescence. The individuals are enabled to see near at hand without the aid of the glasses they formerly used, but this power is acquired at the expense of good distant vision. See paper in *Amer. Jour. Med. Sci.*, April, 1877.—*Translator.*

it often. Very frequently axial myopia of very low degrees can be made out by it.

In the second place, we have the ophthalmoscope, which shows us the displacements which the retina suffers; whether a neoplasm or hemorrhage pushes it forward, and thus produces an axial hypermetropia, or whether it is pushed backward, as in staphyloma posticum, thus causing myopia. It may be well to say that I apply the term staphyloma posticum only to true ectasias, and not to the small crescentic pigmentary atrophies at the edge of the optic disc.

A true staphyloma producing a difference between the level of its base (the macula) and the neighboring parts, is characterized by the difference in the refraction between its centre and its edge; frequently by the form of the vessels, which appear to bend in descending into the excavation; and finally, by the oblique position of the papilla, in the very common cases where it is involved, in part, in the ectasia. The binocular ophthalmoscope renders good service in enabling us to appreciate the real depth of the staphyloma.

In 1873 I pointed out a method, at the Ophthalmological Congress in Heidelberg, which could be used for determining the length of the eye. It is, however, too complicated to be acceptable in practice. Recently Nagel has brought forward another method for the same purpose.*

II. The measurement of the curvature of the cornea and the other refracting surfaces of the eye cannot be made otherwise than by means of the images of reflection which these surfaces furnish.

The ophthalmometer, as is well known, is the means employed in making these measurements.

This instrument enables us to measure the different refracting surfaces of the eye with an exactness that will never be equaled by any other method of measurement. But the ophthalmometer

* *Centralblatt f. Prac. Augenheilk*, Mai, Juin, 1878.

of Helmholtz is not easily manipulated, and is rarely at the disposition of the practitioner.

I have myself constructed an ophthalmometer, based on the principles of my diplometer, which is more simple and much easier managed than that of Helmholtz. By means of this instrument we can measure the curvature of the cornea with so much exactness (the image of reflection can be measured to $\frac{1}{20}$ of a millimeter) that a knowledge of the curvature of the cornea can always be in the hands of the practitioner. And you must remember that this is the most important surface of the whole dioptric system, since it separates the air and the refracting media of the eye; two media whose indices of refraction differ more widely than those of the aqueous humor and crystalline lens. From this fact, the influence of the curvature of the cornea on the course of the rays coming into the eye is much greater than that of the crystalline lens.

It is otherwise for the surfaces of the lens. The ophthalmometer is not applicable for these measurements, and the procedures which could be used for them are very complicated, both as to their execution and the calculations which they require. But if we know that an ametropia is due to an anomaly of curvature of some of the refracting surfaces, we have only to determine the curvature of the cornea; if this is normal, it is the lens which is at fault. When, on the other hand, the curvature of the cornea already gives an explanation of the ametropia, we have no need to occupy ourselves with the lens.

In practice, however, we have, in certain cases, an indirect means of knowing whether an ametropia is to be attributed, or not, to the form of the lens. This is atropinization. If a myopia disappear under the influence of atropine, we know that it is due to an anomaly of curvature caused by undue convexity of the anterior surface of the lens. This, however, is not a case of pure myopia. The myopia which is caused by spasm of accommodation is called *apparent*. It is only a true ametropia from anomalous curvature

when the lens retains its convexity after the paralysis of accommodation.

If we find a myopia with loss of accommodation, brought about suddenly through a trauma, or even without assignable cause, we may know at once that there is a partial luxation of the lens, which, being brought out from under the action of the zone of Zinn and left to its own elasticity, assumes a more convex form.

III. It is not possible to practically determine the index of refraction of the aqueous humor, the lens and vitreous humor, but the researches in physiological optics have shown that the index of refraction of the dioptric media vary but little, and that it is essentially the same in all healthy eyes.

The only known exceptions to this rule are: 1st. General diseases accompanied by great loss of the nutritive fluids of the body, as diabetes, Bright's disease, excessive hemorrhages, etc. 2d. Changes in the structure of the lens, especially those accompanying age and the development of cataract, changes which are revealed, by means of the ophthalmoscope, through a brighter reflex from the surface of the lens.

The fact that in the great majority of cases the index of refraction of the eye can be considered as constant, very materially simplifies our differential diagnosis. In fact, it is usually only necessary to determine whether a given ametropia is to be attributed to an anomaly in the length of the axis of the eye, or an anomaly in the curvature of its refracting surfaces, and one of these factors being known we have, of necessity, the other.

Take, for example, an eye in which we have found a hypermetropia of four dioptries. If the individual is not affected with one of the general diseases we have mentioned, we have only to find the length of the axis of the eye; if it is shortened we know that we have to do with an axial hypermetropia, and not with a hypermetropia from lessened curvature, and there will be no need to measure the curvature of the cornea and lens. In cases where we wish to discriminate between a hypermetropia from deficient

curvature of the cornea and of the lens, we can measure the first directly, and by exclusion arrive at the condition of the latter.

On the other hand, if we know already that a myopia is due to an excess of curvature of the cornea, we lose no time in useless therapeutics, while, on the other hand, excellent results are obtained from continued atropinization, in cases where the myopia is caused by an undue convexity of the lens (spasm of accommodation). Finally, if we are dealing with that form of progressive axial myopia of which we have spoken previously, we must not expect any great results from atropinization, but should direct our attention to the choroiditis and sclerotitis posterior, and the general conditions which favor their production.

We do not assert that all cases of ametropia are so simple as those related, and that each case can be referred to a single cause. It is evident that many influences can concur in the production of any single case; but this does not invalidate the general fact that there are many forms of ametropia distinctly marked, and several very clearly distinguishable causes; and if account is taken, in each case, of the form and cause of the ametropia, our opinions concerning the prognosis and the therapeusis of these affections will certainly be as exact as they are in the cases that occur under ordinary circumstances in other departments of practice.

LECTURE IX.

ACCOMMODATION.

GENTLEMEN:—As with all optical instruments, the dioptric apparatus of the eye can furnish distinct images of objects only when they are situated at one and the same distance. When the distance is changed the apparatus must be modified.

In a condition of perfect repose the eye possesses its minimum power of refraction (which we will call r). It is then adapted, as we have said, to the greatest distance at which it is able to see, that is to say, to its *punctum remotum*. If we call this distance R, we have as the expression of the refracting power of the eye in a state of rest, $r = \frac{1}{R}$.

The emmetropic eye, therefore, in a condition of complete repose, is adapted for objects situated at infinity, and cannot see those objects distinctly which are near at hand. Its R is at infinity, consequently r is $= \frac{1}{\infty} = 0$.

The hypermetropic eye is adapted for a point beyond infinity, that is to say, for rays converging toward its punctum remotum (*negative*) situated at a distance $-$ R behind it; r is therefore negative ($- \frac{1}{R} = - r$).

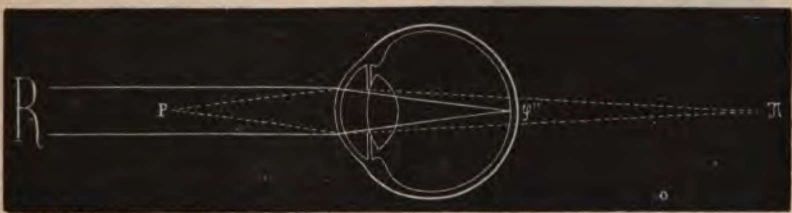
The myopic eye, whose punctum remotum is situated at a certain distance in front of it ($+$ R) is adapted for that distance; its r is positive ($\frac{1}{R} = + r$).

An eye, in a state of repose, does not see at a nearer distance than its punctum remotum, because its dioptric apparatus is *too feeble* to bring the rays coming from the objects at that distance to a focus on the retina.

Take as an example an emmetropic eye (Fig. 18). Its punctum remotum being at infinity, that eye is adapted for parallel rays. It will not see closer, for example, than the point P. The rays coming from P are united, as you see, behind the retina at π. In order that they be united on the retina, it is necessary either to render parallel the divergent rays coming from P, or to increase the refracting power of the eye to such a degree that it shall unite them on its retina in φ'', and not in π.

If you place in front of the eye a positive lens whose focus is at P, it will render the rays coming from P parallel, as if they came from R, that is to say, from infinity. The emmetropic eye by the aid of this glass will, therefore, see as well at the short distance P as it does at infinity without a glass.

FIG. 18.



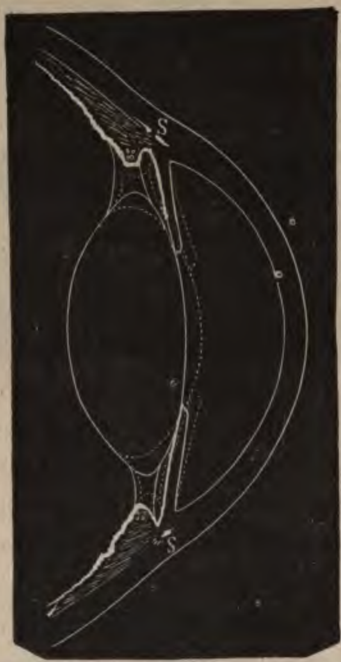
Now, we are able to see near at hand as well as at a distance, and that, too, without the intervention of a convex lens. It is necessary, however, that a certain time—short, it is true, but still appreciable—elapse in passing from the fixation of an object at a distance to one close at hand. We can even feel, especially when the change is effected suddenly, that the eye makes a certain effort in altering its fixation. During this time the effort which we have put forth has added to the dioptric system the convexity necessary to enable us to see near at hand. The increase in the refracting power necessary to change the adaptation of the eye from r to p, an increase which we saw the convex lens bring about in a condition of repose, is effected in the eye itself. It is the crystalline lens which undergoes the change of form necessary to accommodate the eye for objects close at hand. No one at the present time

disputes the fact that the accommodation is due to an increase in the convexity of the lens. The proofs are too numerous and too well known for me to recount them to you here.

As to the manner in which this increase in the curvature of the lens is brought about, experiment has demonstrated the following:—

The accommodation is effected by means of the contraction of the *ciliary muscle.* This muscle is situated in and beneath the ciliary body. It takes its origin in the tissue of the choroid, and is inserted in the border of the canal of Schlemm (S, Fig 19), which forms the fixed point when the muscle contracts. By its contraction the ciliary muscle causes the ciliary body to advance. The zone of Zinn, which is attached to the ciliary body, is relaxed, and the lens which had been more or less flattened by the tension of the zone of Zinn, is left to its own elasticity, and assumes more nearly the form of a sphere.

FIG. 19.



The dotted lines correspond to the state of accommodation.

It is the anterior face of the lens which is principally affected by this change, becoming more convex; the posterior face, incased in the vitreous humor, preserves its form almost unaltered. In this manner the lens adds to itself, so to speak, a positive meniscus, which has the same effect as the convex lens placed in front of it, that is to say, it increases its power of refraction.

If there existed a muscle which would increase the tension of the zone of Zinn, its action would be to flatten the lens, and in this case there would be a diminution of refraction, or in other words, accommodation for objects situated beyond its punctum

remotum. Such a muscle would be of great service to myopes, but unfortunately it has no existence, and there can, consequently, be no *negative* accommodation. When the lens is flattened through relaxation of accommodation, it is only abandoned to the elasticity of the zone of Zinn. The action of the ciliary muscle is confined to increasing the curvature of the lens; accommodation can only be *active* and for near distances.

The nearest point for which the eye can accommodate itself is called the *punctum proximum* (P). The distance between the punctum remotum and punctum proximum is called the *range of accommodation.* It is the distance over which the eye has command by the aid of its accommodation. The force necessary to change the eye in its adaptation from its punctum remotum (r) to its punctum proximum (p) is called the *amplitude of accommodation* (a). Consequently, the amplitude of accommodation (a) is necessarily represented by the difference in the refraction of the eye in a state of complete rest, and at its maximum of accommodation—

$$a = p - r.$$

Since the accommodation has the same effect as a convex lens which would enable the eye deprived of its accommodation to see at its punctum proximum, we can express the accommodation by the number of this lens. The accommodation is, therefore, equal to a convex lens which would give to rays coming from the punctum proximum a direction as if they came from the punctum remotum. What will be the power of that lens?

We have already said that, for the emmetropic eye the focus of the lens should coincide with the punctum proximum, since it should render parallel the divergent rays coming from that point. Its focal distance is, therefore, equal to the distance which separates the punctum proximum from the eye. If this distance is 25 centimeters the lens will have a refracting power of $\frac{100}{25} = 4$ D; the amplitude of the accommodation (a) will be $= 4$ D.

The whole of this refracting power serves to adapt the eye for positive points situated within infinity. We call this positive refracting power p. We have, therefore, for the emmetropic eye—

$$a = p - 0 = p. \qquad (1.)$$

In order to determine the amplitude of accommodation of an emmetropic eye we have only to find the shortest distance at which the individual can read the smallest printed characters.* This distance is the focal distance of the lens corresponding to the amplitude of accommodation. If we divide 100 by this distance expressed in centimeters we have the number of dioptries which, for emmetropia, expresses both the amplitude of accommodation a and its positive refracting power p. If you are emmetropic, and look at a distant object through a concave lens, you experience the same fatigue as when you fix an object close at hand. The concave lens causes the parallel rays to diverge, as if they came from a point nearer at hand, the focus of the lens, in fact. In order, therefore, to see through this concave lens the eye must put in play the same accommodative power as when it looks at an object at the focus of the concave lens. Its accommodation must overcome the influence of the concave lens by increasing the refracting power of the eye precisely in the same degree as the negative lens diminishes it.

We can, therefore, likewise determine the accommodation by means of a *concave* glass. The strongest negative lens through which an emmetropic eye can yet see clearly at a great distance measures the amplitude of its accommodation. An emmetropic eye which can overcome a No. 11 concave in looking at a distance has an amplitude of accommodation of 11 D, and its punctum proximum is situated at $\frac{100}{11} = 9$ cm. in front of the eye, since the concave lens causes parallel rays to diverge as if they came from its focus (9 cm. behind it).

The Accommodation of Hypermetropes.—The hypermetropic

* See Lecture on The Acuteness of Vision.

eye presents, in a condition of repose, a deficiency of refraction. The r which represents this deficit is, consequently, negative $(-r)$. To see at infinity, or, in other words, in order to become emmetropic, the hypermetrope has need of a convex lens, or an effort of accommodation equal to his deficiency of refraction.

A hypermetrope who wishes to see at the same distance as an emmetrope has, therefore, to employ a part r of his accommodation more than the emmetrope. In expressing the amplitude of accommodation, the power necessary to adapt the hypermetropic eye to infinity must evidently be added to that which changes the adaptation from infinity to the punctum proximum. We write, therefore, for the amplitude of accommodation of hypermetropia—

$$a = p - (-\mathrm{r}) = p + r. \qquad (2.)$$

What is the amplitude of accommodation of a hypermetrope of 3 D whose punctum proximum is situated at 20 cm.? He has need, to begin with, of 3 D $= r$ in order to render him emmetropic, and to adapt an emmetropic eye to 20 cm. there is a further need of 5 D ($\frac{100}{20} = 5$). His amplitude of accommodation, therefore, amounts to

$$a = 5 + 3 = 8 \text{ D}.$$

Up to what distance can a hypermetrope of 4 D read who has a power of accommodation of 7 D? Of these 7 D it requires 4 for him to see at infinity, and there only remain 3 D which can be used for near vision. His punctum proximum is, therefore, $\frac{100}{3} = 33$ cm. From equation (2) we have, then, $p = a - r$. You see, therefore, that a hypermetrope of 4 D, though possessing an amplitude of accommodation of 7 D, can see no nearer than an emmetrope who possesses an amplitude of only 3 D. Inversely, if an emmetrope and a hypermetrope see at the same distance, the latter has the greater amplitude of accommodation. Take a hypermetrope of 5 D and an emmetrope, both having their puncta proxima at 16 cm. In order to see at that distance the emme-

trope has need of $\frac{100}{16} = 6$ D; the hypermetrope of $6 + 5 = 11$ D.

The Accommodation of Myopes.—In order to see at the same distance as an emmetrope the myopic eye has need of less accommodation, because, already in a condition of repose, the myopic eye is adapted to a distance for which the emmetropic eye has to accommodate. In order to find the amplitude of accommodation of a myope it is necessary to subtract the refracting power ($+ r$), by which the myope surpasses the emmetrope, from that p, which would adapt the emmetropic eye to the punctum proximum of the myope—

$$a = p - r. \qquad (3.)$$

A myope of 12 D who sees up to 6 cm. ($p = \frac{100}{6} = 16$ D) has an amplitude of accommodation of $16 - 12 = 4$ D; and a myopic eye of 4.5 D which disposes of 5.5 D amplitude of accommodation has its punctum proximum at 10 cm., because the totality of its positive refracting power is composed not only of its amplitude of accommodation, but also of its myopia, which together amount to $5.5 + 4.5 = 10$ D, and which corresponds to a focal distance of 10 cm. ($p = a + r$).

CONVERGENCE AND STRABISMUS.

The accommodation is not the only factor which comes into play in near vision; account must also be taken of the *convergence.*

The closer an object is approached to the eyes, the stronger must be the accommodation and the convergence, in order that there may be distinct and binocular vision. In looking at a distance, on the contrary, the two muscular efforts diminish *pari passu.*

These simultaneous actions of the muscle of accommodation and the internal recti muscles are so intimately associated, the one with the other, that they can scarcely be effected separately; it

is extremely difficult to converge without accommodating or to accommodate without converging. If we could direct the eyes parallel, as for vision at a distance, and make at the same time an effort of accommodation, we could unite stereoscopic photographs in single image without the aid of a stereoscope. This experiment, however, can only be successfully carried out after a long practice, and a given degree of convergence corresponds ordinarily to an equal quantity of accommodation.*

It is for this reason that the punctum proximum of a single eye, the punctum proximum *monocularis*, is a little closer than the punctum proximum *binocularis*. A single eye can accommodate for this near point by means of an increased convergence, during which the visual line of the other eye passes to the inner side of the point of fixation. To this increased convergence corresponds a higher degree of accommodation.

It is this intimate relation between accommodation and convergence which produces most frequently the *convergent strabismus of hypermetropes* and possibly the *divergent strabismus of myopes*.

It was Donders who first called attention to the fact that the great majority of persons affected with convergent strabismus are hypermetropes, and that for the higher degrees of hypermetropia strabismus becomes the rule. He explains the fact in the following manner: the hypermetrope has always need of his accommodation; for objects near at hand this effort becomes more and more difficult; involuntarily he has recourse to an excess of convergence, because he can thus accommodate for a nearer point. But since he converges more than the object fixed requires, he

* The correlation between convergence and accommodation is not, however, absolute. The experiments of Donders and Loring have shown that the two eyes can see distinctly at the same distance, even when weak concave or convex glasses are used. Consequently, without a change of convergence the accommodation can be modified. Likewise, in placing a feeble prism in front of one eye, the angle of the prism being turned outward or inward, we are still able to have binocular vision at the same distance. This proves that the convergence can vary up to a certain point without a modification of the accommodation. The amplitude of accommodation which is possible for the same convergence is called the *relative* amplitude of accommodation.

cannot see with the two eyes at once. One eye or the other is deviated inward, in such a manner that the visual line passes to the proximal side of the object fixed, while the other fixes it accurately. In this way the foundation is laid for a convergent strabismus.

This becomes habitual if the hypermetrope continues near work without supplementing his accommodation by the employment of convex glasses. One fact which speaks strongly in favor of this explanation of the origin of convergent strabismus is, that recent cases of strabismus are cured by the simple correction of the hypermetropia by means of convex glasses.

Donders explains in an analogous manner the tendency to *divergent squint* which is found in *myopes.* A myope demands but little accommodation. Now, we can most easily relax the accommodation by converging as little as possible. When this tendency is pushed to excess it ends in the exclusion of one eye from vision, and renders the visual lines for near vision nearly parallel, and for distant vision divergent. This is the beginning of the strabismus divergens which shows a tendency to increase, especially when it is confined to one eye.

Possibly the divergent strabismus is but an exaggeration of the insufficiency of the internal recti, of which we have spoken in the fifth lecture, an insufficiency which is itself only the result of fatigue of these muscles.

LECTURE X.

THE INFLUENCE OF AGE ON THE AMPLITUDE OF ACCOMMODATION.

GENTLEMEN:—We have said that the accommodation depends, on one hand, on the contraction of the ciliary muscle, and, on the other hand, on the elasticity of the lens. As age advances the ciliary muscle loses, by degrees, its contractility, and the lens its elasticity. These two factors—the feebleness of the ciliary muscle and the increasing hardness of the lens — have necessarily a restricting influence upon the accommodative power.

It is somewhat strange that this diminution of the accommodating power does not wait for the physiological, so to speak, decrepitude which constitutes old age, but begins at a time when all the other faculties are progressing in their development. Already, at the tenth year, the accommodation power begins to grow feeble, and its amplitude to diminish.

Donders, who discovered this fact and established the laws that govern it, has given a diagram which represents the *amplitude of the accommodation at the different periods of life* (Fig. 20).

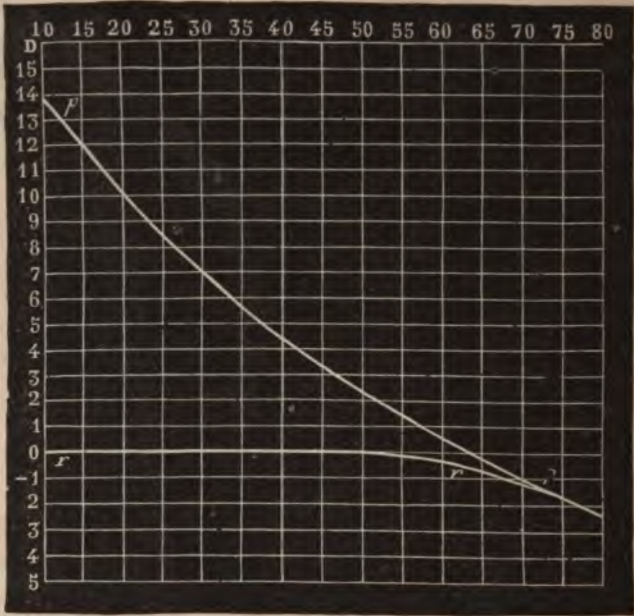
The figures in the horizontal line of the diagram indicate the ages, and those in the vertical line to the left the corresponding dioptries.

The curve *r r* corresponds to the refraction of the eye in a condition of repose, that is to say, to its *minimum* of refraction; or, expressed otherwise, to the refracting power which the eye represents when adapted to its punctum remotum.

This does not change, as you see, up to the age of fifty years, but from that time on it diminishes; the emmetrope becomes

hypermetropic; the hypermetrope more hypermetropic; the myope loses a part of his myopia, and may become, according to its degree, emmetropic, or even hypermetropic.

FIG. 20.



The curve p p indicates the maximum of refraction of which the eye is capable, that is to say, the sum of the refracting power which the eye represents in a state of repose, and what it is able to add to itself by putting into play all its power of accommodation, or, expressed yet differently, the refracting power which the eye possesses when it is adapted to its punctum proximum. As you see, "*p*" diminishes gradually, and becomes, from the age of sixty-five, feebler than the minimum of refraction was in the preceding years. In spite of this, however, there yet remains some accommodative power so long as the two curves do not meet, because the passive refraction of the eye also diminishes from the fifty-fifth year. It only ceases at the age of seventy-three years, when the two curves meet.

The *amplitude of accommodation* is evidently represented, for each age, by the number of dioptries comprised between the two curves, on the vertical line corresponding to the age, in accordance with the formula

$$a = p - r.$$

From this we obtain, for the amplitude of accommodation, the following table:—

TABLE I.

Age.	Amplitude of Accommodation. a.
10 years,	14.
15 "	12.
20 "	10.
25 "	8.5
30 "	7
35 "	5.5
40 "	4.5
45 "	3.5
50 "	2.5
55 "	1.75
60 "	1
65 "	0.75
70 "	0.25
75 "	0.00

The amplitude of accommodation is absolutely the same for ametropia as for emmetropia, and the figures of the series apply indifferently to all forms and all degrees of ametropia. The amplitude of accommodation, a, is the same for all. But p, the positive refracting power of the eye, is not the same. This is equal to the sum of the refraction which the eye presents in a condition of repose (r) and that which it can add by means of its power of accommodation—

$$p = r + a.$$

It is only for the *emmetrope* that the positive refracting power of the eye—that is to say, the refracting power which the eye

represents when adapted to its punctum proximum—is equal to the amplitude of accommodation ($p = a$).

In the *hypermetrope*, where r is *negative*, $p = a - r$; because the punctum remotum of the hypermetropic eye is, as we have seen, negative. A portion of the amplitude of accommodation must serve to correct the hypermetropia.

For the *myope*, on the other hand, r is *positive*, because, in a state of repose, the eye already represents a quantity of positive refraction; the total amount of the latter, then, becomes $p = a + r$.

The distance of the punctum proximum from the eye is equal to the *focal distance corresponding to the totality of the positive refracting power* (p).

It follows from this that, in spite of the equality of the amplitude of accommodation, the punctum proximum is not situated at the same distance in the different states of refraction. With the same amplitude of accommodation, the punctum proximum is always further removed in hypermetropia than in emmetropia, and further in emmetropia than in myopia.

Thus, for an emmetrope of twenty years we find $p = a = 10$ D. Therefore P, the distance of the punctum proximum from the eye, $= \frac{100}{10} = 10$ cm.

A hypermetrope of 4 D will also have, at the age of twenty, an amplitude of accommodation of 10 D, but his punctum proximum is further removed than that of the emmetrope. We will have, therefore, in hypermetropia—

$$p = a - r = 10 - 4 = 6 \text{ D},$$

which gives as the distance of the punctum proximum, P, $\frac{100}{6} =$ 16 cm.

A myope of 4 D, on the other hand, will have, at the age of twenty, a total refractive power—

$$p = a + r = 10 + 4 = 14 \text{ D};$$

and his punctum proximum is, therefore, situated at—

$$P = \tfrac{100}{14} = 7 \text{ cm}.$$

The distance of the punctum proximum corresponds, then, in emmetropia, to the focal distance of the lens which represents its amplitude of accommodation, for reasons which we have already set forth. The following table shows this distance at different ages in emmetropia:—

TABLE II.

Years.	Ampl. of Acc.	Distance of Punct. Prox.
10	14 D	7 cm.
15	12 "	8 "
20	10 "	10 "
25	8.5 "	11.7 "
30	7 "	14 "
35	5.5 "	18 "
40	4.5 "	22 "
45	3.5 "	28.6 "
50	2.5 "	40.5 "

At the age of fifty-five years the emmetropic eye begins to be hypermetropic, and when, even at sixty years, it possesses an accommodative power of one dioptry, its punctum proximum is not situated at 100 cm., because a part of its accommodation must be used to correct its acquired hypermetropia, which amounts to one-half of a dioptry. It requires this amount of effort to bring its punctum remotum to infinity. There remains to it, therefore, only one-half of a dioptry to bring its punctum proximum from infinity to a finite distance, and this is found at $\frac{100}{0.5} = 200$ cm. from the eye.

In order to find the position of the punctum proximum of ametropes, we have only to determine the maximum power of refraction which the eye possesses (p) according to the rules already laid down, and the focal distance of the number of dioptries, which represents p, will give the distance of the punctum proximum P. I should say that in order to find the positive refracting power of hypermetropia we must subtract from the p of emmetropia the number of dioptries which represents the

hypermetropia, while in myopia we must add to this the number of dioptries which constitutes its excess of refraction.

Take, for example, a hypermetropia of 3 D at thirty years of age; where is the punctum proximum? The p of the emmetrope at that age is, according to the diagram (Fig. 19), and according to table I, equal to 7 D. Diminish this by 3 D and the p of our hypermetrope will be $7 - 3 = 4$ D, of which the focal distance is 25 cm.; that is to say, P, the distance of the punctum proximum, sought.

In fact, the amplitude of accommodation of a hypermetrope of 3 D at thirty years is the same (7 D) as that of an emmetrope of the same age. But the first must use 3 D to neutralize his fault of refraction. There only remains to him, therefore, 4 D of positive refraction.

What is the distance of the punctum proximum of a myope of two dioptries at the age of thirty years?

This degree of myopia represents already a quantity of positive refraction of 2 D; to this there is added 7 D amplitude of accommodation, which corresponds to the age of thirty years, which gives $7 + 2 = 9$ D. The focal distance of 9 D is $\frac{100}{9} = 11$ cm., which represents the distance P of the punctum proximum; or, according to our rule, p of the emmetrope being 7 D, that of the myope of 2 D is $7 + 2 = 9$ D, the focal distance of which is 11 cm.

The march of the punctum proximum is so regular that we are able to determine from it, with considerable precision, the age of the individual, by taking into account the state of refraction of the eye.

PRESBYOPIA.

In removing itself further and further from the eye, the punctum proximum must finally pass beyond the distance at which we usually read and write. When the punctum proximum has

passed this limit we are evidently restricted in our work. Even at a period when the total effort of our accommodation yet suffices to keep the punctum proximum at the customary position, but not within it, work at that distance becomes very fatiguing, because it is effected by the aid of the maximum contraction of the ciliary muscle.

The condition of the eye when the punctum proximum has passed beyond the usual distance for work has evidently considerable practical importance. It is for this reason that Donders has given to that condition of the eye when the punctum proximum has passed the usual distance of near work, a special name, *Presbyopia* (from πρεσβυς, old), because this feebleness of vision is a consequence of age. This distance is commonly admitted to be 8″, or 22 to 24 cm.

You see that the definition of presbyopia does not correspond, as do the terms myopia and hypermetropia, to a condition sharply defined. The distance of 22 cm. which has been taken as the point of departure for presbyopia is evidently quite arbitrary. Any other distance, as 20 or 30 cm., could have been taken as well. A man who is accustomed to read at the distance of 30 cm. is not as yet restricted by his accommodation, and does not, of course, feel the influence of age when his punctum proximum is still at 22 or 24 cm. On the other hand, one who usually brings his work up to 18 cm. becomes presbyopic much earlier, although the state of refraction in the two cases may be the same.

Moreover, even supposing that most people showed a preference for 22 cm. as the distance for their fine work, it is evident that everybody would not become presbyopic at the same age, because presbyopia depends on the position of the punctum proximum, and, as we have already seen, in spite of the equality of the amplitude of the accommodation, this varies according to the state of the refraction of the individual.

The term presbyopia, however, being of such general use in

practice, I have thought it best to give you a definition of what is meant by it. But I frankly acknowledge that, in my opinion, it would be best to drop the term entirely out of our nomenclature, and to determine simply what lenses the patient has need of, not to see at a certain specified distance, but at the distance at which he is accustomed to use his eyes, or at which his work compels him to see. This can be done by taking account of his refraction and accommodation, as I shall explain to you at the end of this lecture.

We say that presbyopia has been defined by Donders as that condition in which the punctum proximum has passed 22 cm. In order to see at that distance there is, evidently, a positive refracting force required equal to $\frac{100}{22} = 4.5$ D (p). Now, when the eye has need to see at that distance, and when it no longer disposes of 4.5 D of positive refraction, it evidently becomes necessary to increase this by means of a convex lens of such a power as shall make $p = 4.5$ D. This lens will then measure the degree of presbyopia. We can, therefore, complete the definition of Donders by saying that *presbyopia finds its expression in the number of positive dioptries which it is necessary to add to the eye in order to procure a positive refracting power of 4.5 D.*

By glancing at the diagram of Donders (Fig. 19) or at Table I you will see that at the age of forty years the emmetropic eye can no longer dispose of a refracting power of 4.5 D, and, consequently, cannot see closer than 22 cm. From this age onward, therefore, it is said to be presbyopic.

The presbyopia of emmetropia is equal to the difference between the number of dioptries which represents its positive refracting power and 4.5 D. This at the same time designates the number of the glasses which the emmetropic eye must have to correct its presbyopia.

We obtain, therefore, for the presbyopia of the emmetropic eye the following table:—

TABLE III.

Age.	p.	Presbyopia.
40	4.5	4.5 — 4.5 = 0 D
45	3.5	4.5 — 3.5 = 1 "
50	2.5	4.5 — 2.5 = 2 "
55	1.5	4.5 — 1.5 = 3 "
60	0.5	4.5 — 0.5 = 4 "
65	0	4.5 — 0 = 4.5 "
70	— 1	4.5 + 1 = 5.5 "
75	— 1.5	4.5 + 1.5 = 6 "
80	— 2.5	4.5 + 3.5 = 7 "

p becomes negative from the sixty-fifth year, because the line *pp* then passes the line 0 in the diagram. For this reason it is necessary to *add* the value of *p* to 4.5 in order to obtain the degree of presbyopia.

From being nothing at the age of forty years, the presbyopia increases, therefore, one dioptry for every five years up to the age of sixty. From this time on it increases, sometimes one and sometimes one-half of a dioptry in the same time.

Beyond sixty years this calculation no longer holds good, and we must then have recourse to Table III. Thus, the presbyopia of an emmetrope of eighty years is not 8 D, but only 7 D.

For *ametropia* the presbyopia is calculated in the same manner after the ametropia has been corrected, and the number of dioptries which are necessary to correct the ametropia, that is to say, to change it into emmetropia, must evidently be added to those which correct the presbyopia of emmetropia.

Take a *hypermetrope* of 2 D; what number will he require at the age of sixty years in order to see at 22 cm.? He will need, in the first place, 2 D to correct the H, and 4 D more to correct the presbyopia, since he has passed, by 4 × 5 years, the age when presbyopia commences; the total is, therefore, 6 D.

If an individual has a M of 3 D, and is sixty-five years old, how would we proceed to arrive rapidly at the degree of his presbyopia? If he were emmetropic he would require 4.5 D to

see at 22 cm., but in order to make him emmetropic he requires a concave glass of 3 D. These 3 D negative, combined with the 4.5 positive, give 4.5 — 3 = 1.5 D.

You thus see that whereas the hypermetrope always requires glasses stronger than the emmetrope to correct his presbyopia, the myope requires glasses weaker in proportion as his myopia is stronger.

Take a myope of 4.5 D. He will never, so to speak, become presbyopic, because, even deprived of all his accommodation, he still has a positive power of refraction of 4.5 D, because his punctum remotum, to which it is adapted in a state of repose, is situated at 22 cm. He has no reason, therefore, to fear presbyopia, at least not before sixty-five years, the age at which the refracting power begins to diminish, and when the accommodation no longer suffices to render it as strong as it was before. (See Fig. 19: r has passed the line 0, and p no longer reaches it.)

Persons whose myopia is greater than 4.5 D have need of concave glasses in order to see at 22 cm., because even in a state of repose their eyes are adapted for a shorter distance than 22 cm.; and since there is no negative accommodation they have need of negative glasses to see at 22 cm.; in other words, their refraction being always greater than 4.5 D, it must be diminished until it amounts to only 4.5 D.

A myope of 10 D will have need of a concave lens of 4.5 — 10 = 5.5 D in order to adapt his eyes to 22 cm., up to the age of sixty-five, whatever may be his age and the amplitude of his accommodation. Without accommodation his eyes are adapted to 10 cm., and it is only from the sixty-fifth year, the age when the punctum remotum is removed considerably from the eye, that he can use concave glasses of less strength; but he will never have to use convex glasses.

We should commit a great error, then, in giving to all persons glasses which adapt their eyes to vision at 22 cm. Some—and

the number is large—would find them too strong, while others would find them too weak.

It would be very much better in all cases to guide ourselves, in making the selection, by the requirements of the individual and not by any conventional ideas of presbyopia. We are in a much better condition to make this step, now that the introduction of the metric system and dioptries has made optical calculations so remarkably easy. I can assure you that I get along much better in my practice with my new system than with the old plan of a conventional presbyopia.

Thus, if an emmetrope of fifty-five years comes to you and says that his eyes are much fatigued in using them for close work, you ask him at what distance he is compelled to work. He shows you, we will say, 33 cm. as the distance. You say to yourself: To see at 33 cm. requires 3 dioptries of refraction (p). Now, at the age of fifty-five years p of emmetropia is $= 1.5$. He requires, therefore, $3 - 1.5$ D to see at 33 cm. You therefore give him No. 1.5 D convexes, and he will find them very satisfactory, unless there is some diminution of the amplitude of accommodation, the cause of which you will have to hunt for.

A hypermetrope of 1 D, aged forty years, an engraver, asks for glasses which will enable him to see at 20 cm. To see at this distance there are required $\frac{100}{20} = 5$ D (p). At forty years the eye possesses an amplitude of accommodation of 4.5 D. Of these 4.5 D, 1 D is employed in correcting the hypermetropia of the patient. There only remains to him, then, 3.5 D of positive refraction. To obtain the 5 dioptries necessary for vision at 20 cm. we therefore give him $5 - 3.5 = + 1.5$ D.

A hypermetrope of 3 D, aged seventy, asks for glasses to play the piano, that is, to see at 50 cm. You know that at seventy years of age there is no longer any accommodation. You give him, therefore, in the first place, 3 D, to correct his hypermetropia, and $\frac{100}{50} = 2$ D, to adapt his eye to the distance of 50 cm.

I have no need to multiply examples. What I have said to you

on the subject of accommodation will enable you to find in every case, the refraction, the age, the amplitude of accommodation, and the number of the glass which an eye needs for vision at no matter what distance. Only, you must take the precaution to give the weaker numbers of convex lenses to those yet young and not accustomed to wearing glasses; on the contrary, you can give a half dioptry convex more to an aged person whose amplitude of accommodation is feeble or null.

I repeat that, in my opinion, it would be much better to entirely abandon the term presbyopia, for the reasons which I have given you. The definition of presbyopia is based on a distance entirely arbitrary, which is not the same for all persons; habit, and even the kind of work, have a widely various influence on this distance. Thus, some emmetropes, and hypermetropes with good acuteness of vision, are generally accustomed to read and write at a distance of 40 cm. or more, while others, especially myopes and those whose visual acuteness is not good, prefer a shorter distance, 22 cm. or less.

Bookkeepers, draughtsmen and geometers, by preference, keep their work at a great distance, which allows them to take in a great deal of their book or paper at a single glance, while tailors, jewelers, etc., require a much shorter distance.

You must not think that we have devoted too much time to the consideration of the accommodation. You should bear in mind the great importance of near vision in all civilized countries, and not suppose that it suffices to choose, or have your patient choose, convex glasses which appear to him the best for seeing near at hand, saying, if they are too weak he can change them by and by; if they are too strong they will all the better relieve the accommodation. No, there is a real and an eminently practical value in taking an exact account of the amplitude of the accommodation of the patient.

The amplitude of accommodation is, indeed, so to speak, the dynamometer (the measurer of force) of the ciliary muscle, and

this, in its turn, is the most precise index of the function of the third pair of cranial nerves, which supplies, among other parts, the ciliary muscle. A defect in the amplitude of the accommodation thus becomes, very frequently, a very important symptom, especially of a diphtheritic, rheumatic or syphilitic paralysis, or a cerebral trouble, the beginning of which might escape us but for an examination into the condition of the accommodative power.

LECTURE XI.

ACUTENESS OF VISION.

GENTLEMEN:—The *refraction* of the eye and *visual acuteness* are frequently confounded. They are two very different things, however, and should be clearly distinguished from each other, although in practice we are accustomed to determine them together.

The *refraction* is simply the function of the *dioptric apparatus; visual acuteness*, on the other hand, is a function of the *nervous apparatus* of the eye.

Refraction may be perfectly normal without the eye being able to see, if the nervous apparatus does not perform its function properly; while the acuteness of vision can be normal, in spite of great anomalies of refraction, if these latter are corrected.

We can determine the refraction of all eyes, even of the dead eye; the acuteness of vision, on the contrary, can only be determined on the living eye, and it is further necessary that this living being express itself clearly in regard to the luminous impressions which it receives.

Acuteness of vision is for the retina what tactile sensibility is for the skin, and we determine the condition of the two functions in an analogous manner: We seek in both for the *smallest distance between two points which can be perceived separately.* For the skin we use the mechanical pressure of the two points of a pair of compasses; for the retina the impression produced by the *retinal image of two luminous points.*

The determination of the acuteness of vision consists, therefore, in the determination of the smallest retinal image the form of

which can be distinguished. I ask you to mark the restriction: It is not simply *the smallest retinal image perceived* which gives the measure of the acuteness of vision, but the smallest whose form is *distinguishable.*

The smallest retinal image is a point the perceptibility of which depends solely on its luminous intensity. One luminous point does not measure the visual acuteness—the distinction of forms—but the perception of light, the faculty which the retina possesses of distinguishing differences of brightness.

The acuteness of vision, the faculty of the retina to perceive forms, depends on many conditions—

1. Primarily, on the *sensibility of the retina.*
2. On the *adaptation of the retina.*
3. On the *general illumination.*
4. On the *sharpness of the retinal image.*
5. On the *intensity of the illumination.*

The *adaptation* of the eye to the illumination under which it acts is a condition which it is necessary to take into account in all experiments relative to the sensibility of the retina (distinction of degrees of clearness and of colors). In passing from an illumination of a less to one of a greater intensity, or inversely, it takes a certain length of time (about twenty-five minutes) for the retina to become accustomed to the altered illumination, and to put itself in harmony with it. We know that the acuteness of vision varies with the *general illumination* up to a certain degree of intensity, as that of a clear, sunny day; the two then vary in a direct proportion, but when the illumination passes a certain limit of intensity, the acuteness of vision diminishes instead of increases.

The *sharpness of the retinal image* depends, essentially, on the transparency of the dioptric media, the regularity of their surfaces, and the adjustment of the eye to the distance of the object.

The luminous intensity of the retinal image depends, also, upon the transparency of the dioptric media. It is, in other words, proportional to the luminous intensity of the object, and to the

difference in brightness between this and the background against which it is seen.

Before commencing the examination of the functions of the retina an account must be taken of the intensity of the general illumination; it must be measured. The simplest photometer is the acuteness of vision of a normal eye which we can, in this case, consider as proportional to the illumination.

Before undertaking the examination of the visual acuteness of another eye we should determine that of our own; and if, for example, it is only $\frac{4}{5}$ of that which is usually found, we shall have to multiply the figures of the visual acuteness of the patient examined by $\frac{5}{4}$ in order to obtain his actual acuteness of vision.

We must allow, moreover, the eye under examination to adapt itself to the general illumination, and it must be accommodated for the distance of the object looked at. This latter must be placed in the simplest and most favorable conditions to be easily distinguished by choosing one that is black on a white ground or white on a black ground.

The results of numerous experiments have shown that it is necessary that the two points of a retinal image, in order to be clearly distinguished from each other, be separated by a distance of 0.00436 mm. Such a retinal image corresponds in the normal emmetropic eye to a visual angle of $1'$.

It is upon these data that Snellen has based his "test-types" for the determination of the acuteness of vision. He has taken as the test-objects Latin letters: letters, because they are forms most widely known, and which, in spite of the variety of their figures, are easy to describe; Latin letters, because they are the simplest and most common. Snellen's idea was to have these test-letters formed in such a manner that in order to be recognized they required that the eye should distinguish two points separated from each other by an angle of $1'$; the breadth of the black lines forming the letter, as well as the intermediate white spaces, should be just $\frac{1}{5}$ the diameter of the whole letter.

Each series of his letters is marked by a number which indicates in meters (formerly in feet) the distance at which the letter appears under an angle of 5′.

It is held by Snellen that in order to distinguish one letter from another the eye must be able to distinguish the spaces between the lines which correspond to a visual angle of 1′. This is true for certain letters, as, for instance, to differentiate between **G** and **O**, where the eye must distinguish the white space which interrupts the circle in **G**. The same is true for **F** and **E**, but the principle is not applicable to the other letters of his series.

The interlinear spaces correspond to $\frac{1}{5}$ the height of the whole letter. We can therefore say, in general terms, that the distinctness of the letter depends on the perception of a retinal image of 0.00436 mm.

The scale of Snellen contains a series of letters corresponding to all distances, from 32 cm. up to 60 meters. An eye which distinguishes No. 7 at 7 m. should distinguish No. 10 at 10 m., No. 60 at 60 m., etc. What we want now to know is the most convenient distance for determining the visual acuteness.

In the lecture on refraction we saw of what great advantage it is to determine the visual acuteness and the refraction at the same time.

We determine the refraction at such a distance as shall exclude the accommodation as much as possible. For this a distance of 5 or 6 meters is necessary. We therefore place our scale at 6 m. and see (successively on each eye) what are the smallest characters which can be distinguished.

In order to see at this distance without accommodation the eye must be emmetropic. If it is not, we must render it emmetropic by a correcting lens. The correcting lens, therefore, indicates the degree of its *ametropia*, and the smallest character seen distinctly its *visual acuteness.*

Thus, a normal eye should distinguish at 6 m. all the characters of Snellen's No. 6. If it only distinguishes No. 12—those which

ought to be seen distinctly at 12 m. because they are twice as large—the visual acuteness is only one-half the normal ($\frac{6}{12}$). In order that the same eye recognize the letters of No. 6 it must be brought up to 3 m. If it distinguishes No. 7 at 6 m. its visual acuteness is $\frac{6}{7}$; but if it sees not only No. 6, but even No. 4, at 6 m., the number which we have the right to bring up to 4 m., its visual acuteness is evidently greater than normal—it is $\frac{6}{4}$.

This not infrequently happens. You will find many young people who enjoy an acuteness of vision greater than that which Snellen has taken as the normal. The acuteness of vision of Snellen, however, is not the *maximum*, but is to be taken as the *mean* of the different ages. The maximum acuteness of vision could not, moreover, serve us in practice where we desire to know what is to be considered as normal, and the limits beyond which it is considered to be abnormal.

You have seen that the visual acuteness is always represented by a fraction, the denominator of which is the distance at which the characters should be distinguished, the numerator the distance at which the characters are seen in the case under examination. We call the first D, the second d, and the acuteness of vision V, and then write: $V = \frac{d}{D}$.

When the acuteness of vision with the naked eye is not up to the normal standard, we think at once of an anomaly of refraction, and proceed to the task of correcting it.

An individual who, with a convex glass No. 2, reads No. 8 at 6 m., has a hypermetropia of 2 D and $V = \frac{6}{8}$.

Another who, at the same distance, reads No. 10 with — 3, will have a myopia of 3 D and $V = \frac{6}{10}$.

For persons who cannot read, Snellen has given figures resembling **E**, and which are made on the same principle as the other letters. These are squares, one side of which is lacking. The patient should then indicate to us the side which is open. In this manner we are enabled to examine easily the visual acuteness of children, or of those whose intelligence is not highly developed,

and even of mutes, who can indicate with the hand the direction in which the open side lays.

It is evident that, instead of examining the visual acuteness by the aid of figures of different sizes, placed at the same distance, we can allow the size to remain the same and vary the distance. In this manner a single series of letters would suffice for the determination of V. Take, as an example, No. 6 of Snellen's scale. The individual who reads it at 6 m. has a normal visual acuteness. If we should have to bring it to 4 m., in order that they be distinguished, V would equal $\frac{4}{6}$, etc., in accordance with the formula $V = \frac{d}{D}$.

The single **E** of Snellen would, therefore, suffice to determine the acuteness of V. Instead of varying its size and having different forms, we can change the distance and alter the position of the figure. This proceeding is very convenient where we do not have command of a full set of test-types, but it is inferior to the other mode in cases where we have to bring the figure within 4 m., because then the accommodation comes into play.

But the combination of the two processes—variation in the size of the object, and variation of its distance from the eye—increases considerably the exactness of the examination of visual acuteness. If we have found the series of letters which is clearly made out at a given distance, we can try if by removing it to a greater distance the eye continues to distinguish the letters; for example, an eye sees No. 5 at 6 m., but if it still distinguishes them at a distance of 30 cm. more, V will be not only $\frac{6}{6}$ but $\frac{6.3}{6.0}$.

Snellen's series, though the one most widely known, is not the only scale which has been constructed for the determination of the acuteness of vision at a distance.

Indeed, the principle of the acuteness of vision being given, it is easy to print Latin, Gothic, black or colored letters, etc. However, the scale of Snellen remains the one most generally in use, and it is undesirable to increase the number of these test-objects in order that we may have a *unity* of comparison throughout the

world, which will allow of a comparison between the experiences of different persons in different countries.

The only test-objects which, up to this time, have appeared to me to have a value comparable with those of Snellen, are those of Green and Monoyer. Green objects, and not without reason, that the different numbers of the test-types of Snellen represent a very unequal series of ratios, an inconvenience which Green surmounts in choosing for his scale the numbers which represent a geometrical progression, the common ratio of which is $\sqrt[8]{5} = 7.95$.

The series of Green is composed of twenty-four numbers, and includes all the numbers of Snellen's test-types from CC to I. The following table shows the two series side by side. The numbers represent feet.

Green.	Snellen.	Green.	Snellen.
200	200	8	8
160		6.25	7, 6
126		5	5
100	100	4	4
80, 64	70	3.125, 2.5	3
50	50	2	2
40	40	1.56	
32, 25	30	1.25	
20	20	1	1
16, 12.5	15, 12		
10	10		

As you see, the interval between the two adjacent numbers of Green is always the same. The execution of these test-types is exceedingly good, and they are to be recommended so much the more because the relations between the letters of Green and those of Snellen are very easily established.

Monoyer's test-types, like those of Green, have the same basis in principle as those of Snellen, as far as regards their visual angle and the width of the lines, but they are constructed in such

a manner that the different numbers of the letters recognized at a distance of 5 meters correspond to a difference of $\frac{1}{10}$ of the acuteness of vision. The acuteness of vision, then, instead of being expressed in fractions, as $\frac{5}{6}$, $\frac{3}{8}$, etc., is expressed in decimals—0.1, — 0.2, — 0.3, — 0.4, etc., up to 1.

It is desirable, however, to have characters smaller than those corresponding to the medium acuteness of vision, because we find very frequently eyes whose acuteness of vision is greater than the No. 1 in the scales mentioned. For this purpose it would be easy to add to the scale of Monoyer two or three numbers which give $V = 1.2, 1.5, 1.6$, etc.

You will have seen that the method for determining the acuteness of vision at the same time with the refraction is very simple and practical. But it is not only simple and practical—it is also eminently *rational*. Indeed, it excludes, at least for the greater part, the accommodation, and, as you will see, it puts the retinal images of the emmetrope and ametrope on the same equality as to size.

This last advantage is very great, and in order to appreciate it fully I will add a few words on the *influence of correcting glasses on the acuteness of vision*. It is a fact of common observation that convex glasses magnify whilst concave glasses diminish the size of objects. We would suppose, then, that hypermetropes, by their correcting glasses, obtain retinal images greater than emmetropes and myopes, and that myopes, on the other hand, have smaller retinal images. Correcting glasses would seem, therefore, to completely mar the results of our determinations of visual acuteness, in so far as they change the fundamental condition, viz., the equality in the size of the retinal images coming from the same objects.

But, on the other hand, it is easy to conceive that a short eye, other things being equal, would receive smaller images than a long eye. The smallness of the hypermetropic eye has, therefore, an effect on the visual acuteness the opposite of its correcting glass, and the length of the axis of the myopic eye has an opposite

effect to that of the glass for which it has need. It remains to determine which of these two influences is in excess.

It is a question of great importance in practice whether we have a right to demand of a hypermetrope a visual acuteness greater than that of an emmetrope, simply because he uses magnifying glasses while the other sees only with the naked eye; or whether, on the other hand, we should have a diminished acuteness of vision on the part of the hypermetrope corresponding to a normal retinal perception, because the hypermetropic eye, on account of its shortness, has smaller retinal images.

On the other hand, has a myope who, after correction of his ametropia, reads exactly the same letters as the emmetrope at the same distance, a visual acuteness greater than the emmetrope because he is able to distinguish these characters *in spite* of the diminishing effect of his lens, or should we consider his visual acuteness as defective, and search for some trouble in the dioptric media or at the fundus of the eye, because, on account of the length of the myopic globe, the retinal images are larger, and he ought, therefore, to have a visual acuteness greater than that of an emmetrope?

This question can be solved only by means of calculation; but the aim of these lectures, which are essentially practical, causes me to abstain as much as possible from mathematical deductions, and I can only give you here the results of the researches that have been made by Knapp, Donders, Woinow, Mauthner and myself—results which accord perfectly with each other. The conclusions at which we have arrived are the following:—*

I called your attention, in the first lecture on refraction, to the fact that we can correct ametropia by different lenses according as we place them at a greater or less distance from the eye. Now, since the correcting lens of an axial ametropia is usually placed *in the anterior focus of the eye*, i.e., 13 *mm. in front of the cornea, the retinal image of the ametrope should be of the same size as*

* Landolt in Wecker et Landolt: Traité Complet d'Ophthalmologie I, p, 480.

that of the emmetrope. On the other hand, if we correct hypermetropia by a stronger convex glass placed nearer the cornea, the retinal image will be smaller; it will become larger if we use a weaker lens and place it further from the eye than the point indicated. An analogous effect is produced in the case of myopia; here the diminishing effect of the lens makes itself felt in proportion as it is removed from the anterior focus of the eye, while the magnifying effect of the greater length of the eye is manifest when the correcting lens is approached nearer.

I have been able to verify this fact in a most conclusive manner, both by means of my artificial eye,* and in the living eye—in an anisometrope one of whose eyes is emmetropic and the other hypermetropic, and who on this account is able to compare directly the size of the retinal images which the hypermetropic eye receives by different corrections with those of the emmetropic.

The facts which we have mentioned suffice to show the undoubted advantages of determining the visual acuteness at a distance.

But should we, on this account, entirely exclude the examination of near vision? I think not, *provided* we take account of those important points which have, in a greater or less degree, been neglected by those who, up to the present time, have endeavored to determine the acuteness of vision in this manner.

1. In the first place we should never employ for this purpose bits of reading, because reading is not a certain proof of visual acuteness. Persons who are accustomed to reading are able to guess at the majority of words by their general aspect and their relations to neighboring words, while those who are but little instructed must decipher the letters one by one. These latter, then, find themselves in relatively more unfavorable conditions than the former.

It is necessary, therefore, if we would determine the acuteness

* The Introduction of the Metrical System into Ophthalmology. London, Churchill, 1876.

of vision at a short distance, that we take isolated letters constructed on the same principles as the larger test types. It is also evident that we must make the examinations always at the same distance if we would obtain results exact and comparable. This examination is based on the same principle as that at a distance, *i.e.*, on the equality in the size of the retinal image.

2. Moreover—a most important matter—the vision near at hand is very different in the different states of refraction.

Take, for example, a distance of 22 cm. The young emmetrope will see at this distance with the aid of his accommodation, the presbyope and hypermetrope with the assistance of convex glasses of greater or less strength, according to the power of their accommodation and the degree of their ametropia. The myope whose punctum remotum is found at a greater distance from the eye than 22 cm. will likewise have need of a slight effort of accommodation; only a myope of 4.5 D will be able to see at that distance without any accommodation, and without any correcting glass, while degrees of myopia higher than this will demand the use of concave glasses for seeing at the same distance. Vision, under these various circumstances, is attended with notable differences in the size of the retinal images.

It matters not that you employ the same test objects and place them at exactly the same distance; the emmetrope who accommodates will still have retinal images smaller than the presbyope, who uses glasses, and the presbyope (if he is not completely deprived of his accommodation) smaller images than the myope of 4.5 D. Your result is therefore false, since the basis—that is, the size of the retinal image—is changed in each case. Equality in the size of the retinal images is the "sine qua non" in the determination of the acuteness of vision.

Moreover, by proceeding in this way we do not determine the refractive condition of the eye. The method frequently used, of making the individual read bits of sentences, is, therefore, unsatisfactory and insufficient for the determination of the visual acuteness.

It is possible, however, to obtain in near vision the same advantages as in distant vision—equality in the size of the retinal images, exclusion of the accommodation, simultaneous determination of the refraction, of the accommodation and visual acuteness. For this purpose we proceed in the following manner:—

We place the test object say at a distance of 23 centimeters (exactly 233 millimeters) in front of the cornea, that is, 22 cm. from the anterior focal point of the eye, which is situated 13 mm. in front of the cornea, the eye being deprived of its accommodation.

It is only the myope, then, whose punctum remotum is situated at 23 cm. in front of the eye, who will be able to see distinctly at this distance. In order to see at infinity, the correcting glass placed at 13 mm. in front of the eye, where lenses are usually placed, should have a focal distance of 22 cm., and therefore a refracting power of 4.5 D.

In order to make eyes having other states of refraction see these test objects we must have recourse, not to the accommodation, but to convex lenses, which we place 13 mm. in front of the cornea.

We should give, so to speak, to all eyes a myopia of 4.5 D. To attain this the emmetrope will have need of No. 4.5 convex, which will render parallel the rays coming from 22 cm. in front of the lens; the hypermetrope will require a lens stronger than the emmetrope, and the stronger in proportion to the strength of his hypermetropia.

A hypermetrope of 2 D will have need of 6.5 D, that is to say, he will require 2 D in order to be rendered emmetropic, and 4.5 D in order to adapt his eyes to the distance of 22 cm. An individual who sees with a convex 7.5 will have a hypermetropia of $7.5 - 4.5 = 3$ D.

Myopes up to 4.5 D will require convex glasses diminished by the degree of their myopia. Take, for example, a myope of 1 D; if he had been emmetropic he would have required 4.5 D, but he will not require so much now, since his myopia already gives him

a surplus of refracting power of 1 D. He requires, therefore, only $4.5 - 1 = 3.5$ D, in order to see the test objects at the required distance.

An ametrope who sees with $+ 0.5$ will be myopic, because he sees with a convex lens weaker than the emmetrope requires, and his myopia will be $4.5 - 0.5 = 4$ D.

The individual who sees without a glass will have, as I have already said, a myopia of $4.5 - 0 = 4.5$ D.

Those myopes, on the other hand, whose excess of refraction is greater than 4.5 D will have need of concave lenses whose numbers added to 4.5 D will give the degree of the myopia. Thus, an eye which can see the near test objects only by the aid of a concave No. 2 will have a myopia of $2 + 4.5 = 6.5$ D, since, in seeing without a glass, it will have an excess of refraction of 4.5 D; if it requires still a concave 2 D, this proves that its refraction is yet 2 D too strong.

You see that in this manner we can easily determine the refraction; but the method offers yet another great advantage, in that it gives to eyes of different refraction retinal images of the same size; only it demands, as does every plan for the determination of refraction, that the accommodation be relaxed, and that the correcting lens be placed in the anterior focus of the eye at 13 mm. in front of its cornea.

In this procedure, indeed, the retinal images of axial ametropias and emmetropia become equal. They are not those which the same eyes secure by the aid of their correcting glasses for distant vision, that is to say, of the emmetrope in a state of repose; but they are equal to those of an axial myopia, the punctum remotum of which is situated at the distance chosen.

One other question which naturally presents itself after these considerations is this: how large should the test object be which corresponds, in my method, to the normal acuteness of vision, that is to say, where the retinal image has a size of 0.00436 mm? In order to furnish so small an image to a myope of 4.5 D, or to an

emmetropic eye armed with a convex glass of 4.5 D, and, moreover, at so short a distance, the object ought not to be large. The calculation gives, indeed, only 0.0645 mm. as the distance between the two points of the object, and, therefore, only 0.32 millimeters as the total height of a letter which an eye endowed with an average visual acuteness is able to distinguish at 23 cm. It is necessary, in order to effect this, to reduce the large test types by means of photography or photo-lithography, which is easily done.

You will notice that the angle which corresponds to the typical retinal image of 0.00436 mm. in the myopic eye, or an eye rendered myopic to the extent of 4.5 D by a concave or convex lens, does not correspond any longer to 1′, but to 55″. You will thus see that it will be more rational to take as the basis, and to measure the acuteness of vision not by the *visual angle* but by the *retinal image.*

This method, like all the other methods for determining the refraction, requires that the accommodation be abolished. And, except by the employment of atropine, it will be more difficult to exclude the accommodation in near vision than in an examination at a distance.

We saw, at our last meeting, that the hypermetrope avails himself of the intimate connection between the convergence and accommodation to increase his power of accommodation by increasing his convergence. We can employ the same principle in an opposite sense; that is to say, we can diminish, if not annul the accommodation, by annulling the convergence. Give the eyes a parallel position, according to the principle Javal has used in his astigmometer. Place the test objects in a stereoscope of desired length, deprived of its prisms. In front of the eye to be examined are the test objects surrounded by a circle; in front of the other eye a black field on which is traced a similar circle. When the fields are united stereoscopically the two circles will be superposed, and the two eyes being directed parallel, the accommodation will be relaxed.

My method offers still another advantage, in that it renders invariable the distance between the lens, the test objects and the eye. This last point is of the greatest importance in determining the acuteness of vision at short distances. Slight changes here produce greater differences in the size of the retinal images than more considerable separations of the test objects in the determination at a distance.

In certain other respects this method is preferable to the other. It enables us to dispense with a great distance for the determination of the visual acuteness and refraction, and to have a more regular and constant illumination. It is easy to illumine the interior of our stereoscope with a regular and normal light, and at the same time exclude light from other sources. The windows behind the patient often interfere very considerably with his vision, on account of their reflection from the surface of the correcting lens.

This method can serve us in yet other determinations. As the strongest convex lens or the feeblest concave lens with which the eye can distinguish the smallest characters and attain to its maximum of visual acuteness gives the *refraction*, so the strongest concave or the feeblest convex lens will give the *power of accommodation*. In distinguishing the letters without a lens the emmetropic eye uses 4.5 D of accommodation. But when it yet sees through a — 1 lens, which requires, in order to be neutralized, an effort of accommodation of 1 D, it disposes of $1 + 4.5 \text{ D} = 5.5 \text{ D}$.

The hypermetrope of 2 D who preserves the maximum of his visual acuteness at that distance in spite of a negative lens of 3 D will have an accommodative power of $2 + 4.5 + 3 = 9.5 \text{ D}$.

A myope of 3 D who sees with — 5 will have an amplitude of accommodation $= 6.5$ D. On account of his myopia he will only require $4.5 - 3 = 1.5$ D to see at a distance of 24 cm.; he has, therefore, called forth $1.5 + 5 \text{ D} = 6.5 \text{ D}$. The myope of 5 D who sees with — 6 the same letters as with a 0.5 will have an

amplitude of accommodation of $4.5 - 5 + 6 = 5.5$ D. In order to see at 24 cm. he will require not 4.5 D but $5.5 - 5 = 0.5$ concave. The one-half a dioptry of the 6 which the lens we have given him contains serves, therefore, to correct the excess of his myopia, and the other 5.5 is employed simply to neutralize his accommodation.

There is no need to multiply examples or explanations, which would be only repetitions of what has been said. My intention was only to show you that our plan would serve, at the same time, to determine the amplitude of accommodation.

For the examination of the accommodation we should place the test objects at the middle of the base of the optometer and close the eye not under examination.

Our apparatus will serve equally for those who wish to determine presbyopia, since the test letters are placed at a distance of 23 cm. You will remember the definition we gave of that infirmity. Presbyopia was defined as that condition of the eye in which it is no longer able to see at 23 centimeters; in other words, it cannot dispose of more than 4.5 D of positive refractive power. While the strongest convex lenses give us the refraction of the eye, the concave lenses the amplitude of accommodation, the feeblest convex lenses give us, directly and without reduction, the degree of the presbyopia.

An eye which sees the test letters without a glass is not presbyopic. An eye which requires 2 D to see them has a presbyopia of 2 D; another which requires 4 D has a presbyopia of 4 D, etc.

I have no need to return to this subject, of which we have already spoken at length.

It is unnecessary to add that in an optometer such as I have proposed it is not required to calculate in each case the number of the ametropia, or the amplitude of the accommodation, or the presbyopia, as I have done in order to the better explain my principle. We read on the apparatus directly the figures resulting from the determination.

This method of determining the visual acuteness is not yet employed in practice, and all those who have determined the visual acuteness by means of bits of reading or small letters have not taken into account the conditions which I have just exposed, and which alone render the determinations exact.

The bits of reading, it is true, are in extended use, and serve generally for a rapid determination of presbyopia, since, as a rule, that which we desire is only to give to our patients such glasses as shall enable them to read and do fine work without fatigue. For this purpose the bits of reading are sufficient. The best are those which Jäger (of Vienna) has published in all civilized languages, and which are distinguished by the exactness of their execution.

LECTURE XII.

PRACTICAL EXAMPLES IN THE DETERMINATION OF REFRACTION, ACCOMMODATION AND VISUAL ACUTENESS.

GENTLEMEN:—You are now acquainted with the principles which should guide you in the determination of the refraction, the accommodation and the acuteness of vision. I shall, to-day, give you some clinical examples, for the double purpose of directly showing you the application of the fundamental principles which I have explained in the preceding lectures, and of giving certain practical suggestions which I could not very well give in my brief exposition of the theory of these subjects without interrupting the thread of the discourse.

Before making an examination of the state of vision, we should always subject the patient to a general inspection, by directing attention in particular to *the conformation of the face and cranium, the distance between the eyes,* their *relative positions,* the *transparency of the dioptric media,* the *diameter and mobility of the pupil,* and especially the *length of the globe of the eye.*

The form of the cranium gives us, in certain cases, indications of the state of the refraction of the eye, in so far as the flat, or dish face as it is called, presupposes hypermetropia, while certain forms of myopia are most frequently met with in persons with long heads; but a sign more valuable than these is the asymmetry of the cranium which nearly invariably accompanies astigmatism (see Lecture VII).

The distance between the eyes concerns us particularly where

we have to order glasses for the patient. It is, indeed, of great importance to separate the glasses by a distance corresponding to that which separates the eyes. It should be equal to this when they are to be used for vision at a distance, a little less if they are to be used near at hand. Moreover, we have already seen, in the second lecture, that in cases where we have insufficiency of the internal rectus muscle, and consequently asthenopia, the distance between the eyes demands our closest attention.

For the same reason we should examine the *direction* of the eyes, a high degree of insufficiency of a group of muscles manifesting itself frequently by a slight divergence or convergence of the visual axes. We should examine, moreover, the equilibrium of the internal and external recti by means of the separate fixation of the index finger, as we have already explained in the fifth lecture. A convergent strabismus will be presumptive evidence of hypermetropia, a divergent strabismus, of myopia.

Troubles of the *refracting media*, such as spots on the cornea, deposits on the anterior capsule of the lens, commencing cataract, etc., will deprive us of the hope of a perfect acuteness of vision, in spite of the correction of the ametropia.

The *diameter and mobility* of the pupil will indicate to us the state of the accommodation, and often give important indications as regards the fundus of the eye. In cases of amblyopia the pupil is frequently more or less dilated, and reacts tardily under the influence of light.

But the most valuable indications are derived from an examination of *the length of the ball*, as we pointed out at the beginning of the lectures on refraction.

After this inspection, which, after a little practice, can be completed in a few minutes, we cause the patient to sit down, his back against the light, in front of the test types placed in a good light on the wall five meters distant, and proceed to the examination of the *acuteness of vision* and the *refraction* of the two eyes successively.

I commence always with the better eye, this giving us the more certain indications, and, in many cases, the nature of the ametropia of the other eye. We cause the patient to cover the worse eye with a screen. This simple proceeding is of considerable importance: in the first place, because it is necessary that the eye be excluded completely from the act of vision, of which we can never be certain so long as he covers the eye with the hand, since patients frequently see through the spaces between the fingers or the space between the nose and hand; moreover, in covering with the hand it is difficult to avoid more or less pressure on the eye, and this pressure, however slight it may be, always influences considerably the vision of the eye and is liable to lead us into error.

We should not allow the patient to close one eye, however gracefully he may be able to do it. You can never know that he is not deceiving himself, and still sees with the eye supposed to be closed sufficiently to supplement the other when it has come to the limits of its visual acuteness. Moreover, in the majority of cases, when one eye is closed the lids of the other are also brought more or less closely together, and this may be another source of error, by masking in part an anomaly of refraction, particularly astigmatism.

You know, indeed, that many myopes (μυειν, to wink the lids), and especially the astigmatics, partially close the eyes in order to see distinctly. In this manner they form a stenopaic slit, which, by diminishing the circles of diffusion, sometimes increases the visual acuteness considerably.

Astigmatics can, on their part, exclude the vertical meridian of the eye, and thus obtain much more distinct retinal images. We should always watch the patient, and insist on his keeping the eyes wide open.

All these precautions being taken, you see what the eye can distinguish without the aid of glasses; afterward, to what degree you are able to increase the visual acuteness by means of spherical

glasses. You then determine the astigmatism, if there be any, and pass on to examine the other eye in the same manner.

The accommodation of each eye is then determined by turns, including the glass which the patient requires for vision near at hand, and finally, the amount of muscular insufficiency.

The ophthalmoscope will complete this examination, showing the real state of the refraction of the eye, and giving an explanation of the amblyopia.

Case 1.—A young woman of about twenty years presents herself, complaining of asthenopia, that is, that her eyes refuse her service when she has worked for some time, and especially in the evening. She is anæmic. The bridge of the nose and the zygomatic regions are flat; slight asymmetry of the face, the left half more developed than the right; direction of the eyes normal; no insufficiency; pupils equal and movable. The left globe does not appear to differ notably from the normal length; at any rate, it is not elongated; the right globe manifestly short.

The patient having told you that the left is the better eye, you examine it first, and you find that it can read, without glasses, No. 5 of Snellen at five meters distance. The acuteness of vision is therefore normal, and the eye is not myopic; but it may be hypermetropic, and overcome its hypermetropia by means of its accommodation.

Try, now, if the acuteness of vision remains the same or improves with a very feeble convex glass, for example, + 0.5: the patient rejects it. There is, therefore, no hypermetropia manifesta, and you write: L. E. V. = $\frac{5}{5}$.

The right eye, without glasses, can only see No. 36 of Snellen's scale (V = $\frac{5}{36}$); with + 1 it sees the same letters, but more clearly, and even those of No. 24; with + 3 V becomes $\frac{5}{12}$. This is, for this eye, the maximum of correction, No. 3.5 impairing the vision. You have, therefore, R Hypermetropia manifesta (Hm.) 3 D, V = $\frac{5}{12}$.

The youthfulness of the patient makes you suspect that a part

of the hypermetropia, in the right eye as well as in the left, is masked by the accommodation. This presumption is further justified by the fact that the two eyes are very soon fatigued by close fixation, as is nearly always the case in hypermetropia.

How can we discover the latent hypermetropia? There are two infallible means—atropinization and the ophthalmoscope. You would not, however, as yet, submit the patient to atropinization, which will deprive her for some days of her power of accommodation, and consequently render her unable to do close work; moreover, it is unnecessary if you can, with facility, determine the refraction by means of the ophthalmoscope. This examination discloses the fact that there is 1 D of H on the left; 4 D on the right. There is, therefore, on the left, as on the right, 1 D H latent.

It would seem that we ought to be able to determine the exact amount of the ametropia by means of the punctum proximum. At the age of twenty years the eye possesses an amplitude of accommodation of 10 D; the emmetropic eye ought then to be able to distinguish the smallest objects at a distance of 10 cm. The hypermetropic eye, on the other hand, will not be able to see so near; thus, a hypermetropic eye of 1 D will only have $10 - 1 = 9$ D of positive refraction, and its punctum proximum will be found at 11 cm. If the hypermetropia of the right eye is 3 D this eye will possess only $10 - 3 = 7$ D of positive refraction, and its punctum proximum will be found at 14 cm.

In our case, where the total hypermetropia is 4 D, the positive refractive power will be $10 - 4 = 6$ D, and the punctum proximum will be situated at 16 cm. You see that if the difference between the manifest hypermetropia and the latent hypermetropia is only 1 D the difference in the position of the punctum proximum is likewise very small, and it will be difficult to use it in determining the state of the refraction by this method, and so much the more as the amplitude of accommodation presents great individual variations.

The same may be said of myopia when we have to determine that portion of the apparent myopia which is due to the accommodation.

To what must we attribute the impairment of visual acuteness in the right eye, in spite of the correction of its hypermetropia? It is not due to the smallness of the retinal images, these being, after correction of the ametropia, of the same size as those of the emmetropic eye. Is it due to a lack of development of the retina, or lack of exercise? Possibly to both. In the high degrees of hypermetropia the retina would appear sometimes, indeed, to be less sensitive than in emmetropic eyes, and this right eye having been, on account of its anomaly of refraction, in a less favorable condition than the left, the individual has always preferred to employ the better eye, neglecting the other to a greater or less extent. But we should not content ourselves with this explanation before we know that the eye is not astigmatic.

Armed with the convex glass No. 3, it should not, if unastigmatic, discover any marked difference between the various lines of the radiating figures of Snellen and Green; nevertheless, we find that the horizontal lines appear to it to be somewhat more distinct than the vertical. It is therefore the vertical meridian which is corrected by the convex No. 3, the horizontal meridian not completely. You place in front of the spherical glass a cylindrical lens of 0.25 D, axis vertical, and there is no difference in the lines. The acuteness of vision is at the same time brought up to $\frac{5}{6}$. Try, now, if, with a cylinder of 0.5 D, it increases; it does not, the patient preferring the 0.25. Then put the spherical and cylindrical lenses in a frame which has a movable ring, and let the patient find the position of the cylinder in which she sees best. You then read off the degree of inclination which the axis makes with the vertical; it is 5°, and with this correction the patient reads some letters of No. 6 of Snellen. You see that the correction of this feeble degree of astigmatism has been sufficient to double the acuteness of vision. Such cases are not rare.

Let us now examine the accommodation. The patient reads the smallest characters of our test-types with the left eye up to 11 cm., with the right up to 15. But the eyes are soon fatigued. It is to this feebleness of accommodation, in conjunction with the anæmia of the patient, that we can refer the asthenopia. We therefore order iron and the use of glasses, as follows:—

L. Convex 0.5 D.

R. Convex 3 combined with convex cylinder No. 0.25, axis inclined 5° to vertical.

And all the symptoms of asthenopia will soon disappear.

You will observe that I did not order a glass correcting the total hypermetropia. Practical experience has taught me that young hypermetropes very frequently have great difficulty in accustoming themselves to the correction of their total hypermetropia. On this account I usually begin by giving them feebler glasses than they require, and ordering stronger ones afterward, if the asthenopia continues.

It is of great importance to cause her to bring her right eye into active exercise. You should advise her, therefore, to read and work half an hour, twice each day, with the right eye armed with the correcting glass, the other being closed.

Case 2.—A mother brings you her young daughter of fifteen years. She has been suffering from a very severe diphtheria, and is very pale. However, she is much better now, but since her convalescence has set in, she has noticed that she can no longer see close at hand, though her distant vision is good enough.

The first fact, the sudden appearance of the difficulty in near vision, causes us to think of *paralysis of the accommodation*, and the second, the conservation of good vision at a distance, renders this supposition almost certain. It indicates, also, that there is neither myopia nor amblyopia.

Indeed, if a young person complains of an inability to see close at hand, that is to say, at about 20 cm., without there is reason to

suppose the existence of amblyopia, it does not prove that there is a paralysis of accommodation, because the subject may be hypermetropic to such a degree that all the power of accommodation is expended to correct the faulty refraction ($-r$) and there no longer remains enough of positive refraction to bring the punctum proximum within infinity. The individual can, therefore, be strongly hypermetropic, but, in such cases there is nearly always astigmatism, or an impairment of sight, and the vision at a distance is no longer perfect.

Paresis of the accommodation in youth is the same as presbyopia in advanced age. A man of fifty years, who sees well at a distance, but not near at hand, is either emmetropic or feebly hypermetropic, and just beginning to become presbyopic. The supposition of hypermetropia becomes the less probable as the individual becomes older. An individual, on the other hand, who can see well neither at a distance nor near at hand—having no other ocular lesion—is hypermetropic, and in a degree the stronger as the punctum remotum is further removed, and the age less advanced.

Persons who say they see well near at hand, but not at a distance, are myopes, and those who do not see either near or at a distance, even with ordinary (spherical) glasses, are astigmatics.

But to return to our young patient; the pupils are very much dilated; by covering and uncovering the eyes they react slowly and very imperfectly. Your diagnosis is made. You have now only to determine the degree of the affection, that is, whether the paralysis of the accommodation is complete, or whether there is only a paresis of the accommodation and its extent.

The patient reads without a glass, with both eyes, No. 5 of Snellen placed at 5 meters; visual acuteness is therefore normal ($\frac{5}{5}$). Nevertheless make a trial of convex glasses; she reads No. 4 with + 3 but not with 3.5; there is, therefore, $H = 3$ D; $V = \frac{5}{4}$. But the correction being incomplete, the patient distinguishes, without a glass, only No. 5 (the circles of diffusion are

not sufficiently great to render the characters illegible, but they render more diffuse those of No. 4 which are smaller).

It is useless to try if the patient reads near at hand, since the accommodation does not suffice to correct the totality of her hypermetropia, that is to say, to bring the punctum proximum to infinity, and it cannot, of course, bring it to a finite distance.

In such a case, find the feeblest convex glass with which the patient has her maximum of acuteness of vision, $\frac{5}{4}$. You find that it is No. 1 D. The patient has therefore preserved an amplitude of accommodation of $3 - 1 = 2$ D, in the place of 12 which corresponds to her age; she has lost, consequently, 10.

What number would you give her for reading and writing at 30 cm. (ordering a tonic regimen to bring back the total accommodative force)? The weakest convex glass which allows her to see at that distance, in order not to leave the accommodation without exercise.

To see at 30 cm. there is required a positive refraction (p) of $\frac{100}{30} = 3$ D. For a hypermetrope of 3 D, deprived of his accommodation, there will be required $3 + 3 = 6$ D; but since the patient still possesses 2 D of accommodation we give her only No. $(6 - 2 =)$ 4.

Case 3.—You have an old man of seventy who complains that the glasses he has used for many years are unsatisfactory. He only began the use of glasses for near work at fifty-five years, which would lead us to suppose that he was slightly myopic, or that he has been accustomed to read and write at a very great distance, since emmetropes usually begin to use glasses at the forty-fifth or fiftieth year for reading and writing; hypermetropes earlier and myopes later.

You determine the state of his refraction and find emmetropia on both sides. V, on the left side, $= \frac{20}{25}$, that is to say, he distinguishes No. 25, of Green, at twenty feet. On the right side $V = \frac{20}{80}$. The emmetropia you find now does not exclude the possibility that the patient was myopic previously. On the

contrary, the diagram of Donders (Fig. 20) shows us that the passive refracting power of the eye (r) diminishes from the age of sixty-five years, and that at the age of seventy it is one dioptry feebler than it was at sixty-five years. Our patient may therefore have had a myopia of one dioptry which, afterward, gave place to emmetropia. The glasses he is using are the old No. 18 (2.2 D). You are astonished that the patient has been able to use these glasses for so long, since he says that he can read large letters with them for a while, though he cannot continue it for any length of time and the light must be very good.

You then ask him to show you how he reads, and find that he reads No. $1\frac{1}{2}$ of Snellen by holding the book at a good distance from the eye, and if he reads by a lamp he places it between the book and the eye. With his No. 18 (old system) he reads at a distance of 40 cm., if not continuously, at least for a time, and the strong light contracts his pupils so that the circles of diffusion produced by the letters for which the eyes are not perfectly adapted become smaller, and the retinal images more distinct. You ask him at what distance he wishes to read, or at what distance he has been accustomed to read. He indicates a distance of about 30 cm., and he tells you that he wishes, above all things, to read any length of time without fatigue. To see at 30 cm. without fatigue he requires 3 D.

In examining each eye separately, you will find that it is only the left eye which reads the small characters at the distance indicated, the other eye, the visual acuteness of which is impaired, only reading the larger ones. This is perfectly natural; if letters for distant vision must be triple the size of those for the other eye he will, of course, require larger characters for near vision.

The acuteness of vision of $\frac{20}{25}$ (Green) in the left eye does not fall below the standard for the age of the patient. At seventy years the transparency of the dioptric media, and the sensibility of the retina have, generally, been reduced so as to diminish the acuteness of vision one-fourth. The oblique illumination shows,

in this case, opacities of the media, the ophthalmoscope senility of the optic nerve. But the other eye, which has only $V = \frac{20}{80}$, is not normal. Cause him, therefore, to fix a small luminous point not far distant from the eye and he will, without doubt, see it multiplied. This polyopia is explained by a commencing cataract.

CASE 4.—A young man of thirty enters your room with his glasses on his nose and his head thrown back in the air. He is myopic; his eyes are not only prominent, as we sometimes find them even in hypermetropes, but large, and particularly long, as you can easily convince yourself by separating and drawing back the lids.

During this examination he tells you that he has a brother and two sisters myopes, and another brother who is not. He has never seen well at a distance, and he has sometimes used the glasses of his older brother.

You ask him if his parents are myopic. "Not at all," he says; his father, especially, has always had excellent sight, since he was seventy years old before he was required to use glasses, and was always able to distinguish the finest characters. This is positive proof of myopia, because an emmetrope of seventy years would require convex glasses.

The glasses which he uses, he tells you, have been selected by an excellent optician, and are the best that he could find. The number of these is $6\frac{1}{2}$ of the old system. He says that he has no affection of the eyes; that, on the contrary, his eyes are very strong; he sees the smallest objects and reads bad print even in bad light. He does not come at all for an examination, but only wishes a collyrium for some neuralgic pains which he sometimes feels in the eyes and forehead, like a kind of migraine.

You examine, as usual, each eye separately, and with so much the greater carefulness because the patient has been, up to this time, his own physician, and is very glib with such scientific terms as irido-choroiditis, pyramidal cataract, gerontoxon, etc.

You begin by taking a book with the finest print, and searching for the greatest distance at which he is able to read it; you finally find it to be 20 cm., which corresponds to 5 D.

At a distance he can make out no letters of the scale; you commence by giving him a concave No. 4; he reads then up to No. 0.4 (Monoyer); with 4.5 he reads some letters of No. 0.5; with 5, all of line No. 0.6, with the exception of **O** and **E**, which, however, are not hard to make out; on the other hand, he can decipher a few of No. 0.7. The No. 6 glass seems better, but he can read no further with it. Myopia of the left eye is therefore equal to 5 D; V about 0.6–0.7. The same is found on the right side.

His glasses are No. $6\frac{1}{2}$ of the old system, which corresponds to the new number 6. If you test them you will find that the glasses are even stronger than their number indicates, and that they correspond to the No. 6.5 of the new system (6 of the old system instead of $6\frac{1}{2}$). He has, therefore, always worn glasses stronger than his myopia has required; and no doubt they have fatigued his eyes considerably, on account of the effort of the accommodation which they have demanded. Now, at the age of thirty years, when the accommodation is not so powerful as at twenty, this fatigue becomes intolerable, and the patient finally acknowledges that, in spite of his excellent number, he can no longer see so well at a distance as others.

To what can we attribute his amblyopia? There has probably been some choroidal troubles, frequent causes of myopia and amblyopia, which are readily appreciated by the ophthalmoscope. But first see if he has no astigmatism, which the confounding of letters leads us to expect.

You place the card of radiating lines before him at a distance of about five meters and try his left eye with concave No. 5 spherical; he tells you, after a certain "searching," that he sees distinctly only the line on the right side, inclined 10° to the vertical, while all the other lines are more or less indistinct, espe-

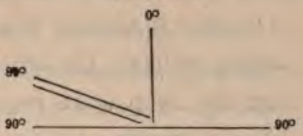
cially the one which is perpendicular to the direction indicated, that is to say, inclined on the left 80° to the vertical.

There is, therefore, regular astigmatism; one of the two principal meridians is inclined on the right 10° from the vertical, the other on the left 80° from the vertical, and this latter is myopic to the amount of 5 D, since with — 5 the lines perpendicular to its direction are seen clearly and distinctly.

In order to determine the refraction of the other principal meridian you combine with the spherical — 5 a convex cylindrical No. 0.25, axis inclined on the left 80° to the vertical. The patient does not see so well. Therefore we judge this meridian to be more myopic than the other. You now try the concave cylinders, beginning at 0.25.

The patient, we find, finally, sees best with — 0.75 axis 80° on the left;* all the lines of the figure appearing to him to be equally clear, and the acuteness of vision, which we should always try as the final test of our correction, has become 1 exactly. For the right eye you find the same ametropia, only the inclination of the astigmatic meridian is symmetrical to that of the left eye, that is, the inclination of the axis of the No. 0.75 cylinder must be 80° on the right.

FIG. 21.



Our examination has proved to us that the difference in the refraction of the two meridians is 0.75 D. This is incontestable, but are we so sure that the myopia in one is 5 D and in the other is 5.75 D? No; because a portion of the myopia may be due to an effort of accommodation. In order to convince yourself of this, combine with the cylindrical 0.75 a moderately strong spherical glass, and you will be astonished to find that even with a spherical — 4 combined with a cylindrical — 0.75 the patient sees as well as with the No. 5. He will tell you, moreover, that he sees much

* We indicate the inclination of the axis by a double line and in its relation to the vertical 0°, as shown in the diagram (Fig. 21).

larger, and that this glass fatigues his eyes much less than his own glasses.

It very frequently happens that astigmatic myopes, who, never seeing distinctly, are led to use stronger and stronger concave glasses because they mistake the smallness of the object for distinctness.

The muscles of accommodation are, therefore, thrown into a state of permanent contraction; they suffer, in consequence, oftentimes, from an extreme asthenopia, accompanied by neuralgic pains and photophobia, and what is still worse, choroiditis, which is often the cause of the myopia, finds in this constant irritation of the ciliary region an aggravating factor.

After having verified the degree of myopia by means of the ophthalmoscope, which is found to be 4 D, you order for the patient, for distant vision, the following glasses:—

L. E. Spherical concave No. 4 combined with a concave cylindrical 0.75, axis 80° to the left.

R. E. Spherical concave No. 4 combined with a concave cylindrical 0.75, axis 80° to the right.

In writing the order for cylindrical glasses it is always well to make a diagram of the spectacles as they appear when lying on the table, with their branches in the air, just as the patient will look through them; that is, with the lens on the left side corresponding to the left eye, the right lens to the right eye. On this the degree of inclination of the axis of the cylinder to the right or left of the vertical can be indicated, and any misunderstanding or mistake avoided.

In order to see near at hand you give him only the cylinders which correct the difference of refraction in the two meridians, that is, concave cylinders No. 0.75, with axes directed as above indicated. These will be found to work admirably; objects which he looks at will appear more sharply defined, letters blacker, and what is of more consequence, he can remove objects much further from him, though the glasses have but a feeble action, and only in one meridian.

You give him, moreover, such hygienic advice as we should never neglect in dealing with myopes. We have already pointed out what this should be, in the lectures devoted to diagnosis.

Your patient leaves you in serious doubt of the infallibility of his optician and his own ideas of irido-choroiditis and visual power, but, on the other hand, distrustful of the discovery which you have made as to the condition of his eyes: "no collyrium and an order for complicated glasses!"

He returns after a short time. He has tried to follow your advice; for reading all goes well; for distant vision it is well also, but it is impossible for him to play the piano. If he uses his glasses for near vision he must bring himself too close in order to see the notes distinctly. This is evident, since his myopia is 4 D after correction of the difference in the two meridians, and in order to see at the distance of the notes, 50 centimeters, he must have $\frac{100}{50} = 2$ D. Although it will not be necessary to completely neutralize his myopia, it must be diminished by 2 D ($4 - 2 = 2$). You will therefore give him for both eyes spherical concaves No. 2, with concave cylinders 0.75, axes as above. All difficulties will then disappear.

Case 5.—You have here a young man of about sixteen years. He has never seen very well, either at a distance or near at hand, and yet he has never been able to find any glasses which would correct his faulty vision. Since he has been following a course of mathematics the difficulty in his vision has become a serious obstacle, in the first place because he cannot see the charts on the wall, and in the second place because he has the greatest difficulty in making geometrical drawings.

His eyes present no alterations visible to the naked eye; they are neither excessively short nor excessively long. But you cannot help being struck with the asymmetry of the face, which is quite pronounced. Your thoughts, therefore, turn immediately to astigmatism.

You now examine the left eye, according to the rules already pointed out. Without a correcting glass he reads, but confusedly

and with difficulty, the first two lines of No. 1 and 0.2 (Monoyer), and if he attempts to make out more he commits very great and curious errors. He confounds letters which have no resemblance to each other, and sometimes makes out a complicated letter while he cannot distinguish a very simple one by its side.

A convex No. 1 increases the visual acuteness to 0.2 or 0.3, but no more; stronger convex glasses diminish it.

Place before him the radiating figure and put the convex glass No. 1 before his eye. He sees only one line distinctly and that not perfectly black. This is the vertical line; all the others are confused.

You add a convex cylinder 0.5, with its axis in the direction of the line which is least distinct and perpendicular to the line which appears clearest; the lines then appear more confused. The vertical meridian does not, therefore, appear to be hypermetropic, since the horizontal lines and those approaching it are not clearer with + 1 spherical, and are even less distinct with a + 0.5 cylindrical. But by turning the cylinder before the eye you will find a position in which the vertical line appears more distinct than with the spherical alone. This is when the axis of the cylinder is vertical. The horizontal meridian is, therefore, more hypermetropic than 1 D.

Now try cylindrical glasses still stronger, and the vertical line will become yet more distinct and the neighboring lines will also become clearer. Finally, with cylindrical + 4, all the lines are clearly made out, with the exception of the horizontal and two or three of those nearest it.

With this combination, spherical + 1 and cylindrical + 4 axis vertical, the acuteness of vision becomes 0.5. This is truly a wonderful result, compared with that obtained with the spherical lens alone. But you must not content yourself with this, knowing well that the vertical meridian is not corrected, since the horizontal lines do not appear as clear as the vertical.

You already know that this meridian is not more hypermetropic than 1 D. Try and see if it is emmetropic, that is to say, if all

the lines are clear and distinct without any other correction than that in the horizontal meridian. This has a hypermetropia of $4 + 1 = 5$ D (4 cyl., 1 spher.). With a cylindrical + 5, axis vertical, the lines are seen about as before, possibly more distinctly, and by adding a negative cylinder of 0.75 D, axis horizontal, the horizontal lines become as distinct as the others, and the acuteness of vision comes up to 1. You have to do, therefore, with a mixed astigmatism, hypermetropia of 5 D in the horizontal meridian, myopia of 0.75 D in the vertical, and you order glasses: convex cylinder No. 5, axis vertical, combined with a concave cylinder of 0.75 D, axis horizontal.

The right eye is found in a similar condition.

I have found exactly this degree of astigmatism with the same acuteness of vision, 0.2 before and 1 after correction, in one of our most distinguished colleagues, only the axes of the principal meridians are somewhat inclined.

It is an interesting fact that Dr. B. can counteract his astigmatism by means of a concave cylinder of 5.75 D, axis horizontal, by calling into play his accommodation. In this case an accommodation of 5 D corrects the hypermetropia of the vertical meridian, while it increases the myopia of the horizontal meridian in an equal degree, and this latter then becomes $0.75 + 5 = 5.75$ D.

But this case offers another point of great interest. He can completely neutralize his astigmatism and render his visual acuteness normal by applying the tip of his finger on a point of the globe situated upward and outward, and a little behind the border of the cornea, about on a level with the equator of the lens. The pressure exerted on this point is in the direction of one of the principal astigmatic meridians.

But I will not multiply examples, convinced that with the indications contained in the preceding lectures you can, without difficulty, determine the nature and degree of the various forms of ametropia; and that the examples just given, which exemplify the most complicated cases, will assist you in those of greater difficulty.

LECTURE XIII.

EXAMINATION OF THE PERCEPTION OF COLORS.

GENTLEMEN:—We propose to-day to enter into the study of the perception of colors. This is, as you shall see by and by, one of the most important chapters in the study of the functions of the organ of vision, and so much the more on account of the extent of its application beyond the limits of ophthalmology pure and simple. Its history is not a long one, for it has been developed almost under our very eyes.

Ancient history has left us no study on the subject except the treatise of Pliny, where the latter upbraided his fellow citizens for being, in painting, inferior to the ancients, who only recognized four colors, while in his time they were in possession of a very large number.

Afterward there appeared the great treatise of Leonardo da Vinci on the art of employing colors, the first edition of which was published in Paris in 1651. The interest of this most important work is confined principally, however, to painters.

In reality, it is from the time of Newton that we must date the study of the physics of colors. It is to him and to Thomas Young that we owe the scientific basis of our present knowledge of the subject.

As to the anomalies in the perception of colors, they were neither known nor studied previous to 1830, when Dalton published his observations on *achromatopsia*.

Himself affected with a peculiar kind of achromatopsia (he was unable to distinguish red) he described with great exactness his condition, and drew to this the attention of *Savants*. From this

fact comes the name *Daltonism*, which has been too freely applied to all affections of this kind.

You will observe how near to us the date of this discovery is; and although the number of cases in which we find some abnormality in the perception of colors is already quite considerable, we are every day more astonished at the frequency of this defect of vision. One fact is, in particular, an evidence of this: In England, Norway and Sweden a series of railway accidents have happened under precisely the same conditions; collisions of trains, in spite of the signals which indicate an obstacle on the track. On interrogating the engineers, they asserted that they did not recognize the signal, which is green when the way is free and red when there is an obstruction. The vision of these engineers was then examined, and it was found, to the great surprise of all, that there were many who could not distinguish red from green.*

The employés on the railways were then examined, and so large a number were found affected with anomalies as regards the perception of colors that they were compelled to contrive signals of another character.

Such an examination was also made in Holland and Germany. The same may be said for some companies in France; others have done away with all colored signals except red. We shall see further on whether this will suffice. I am persuaded that after a time all the railway companies will cease to use colored signals, and employ only those with different outlines.

But the examination of the perception of colors has otherwise a very wide application. Indeed, this function is found altered, not only in many affections purely ocular, but also in a considerable number of diseases affecting, either primarily or secondarily, the brain and spinal cord. Among these I will cite locomotor-ataxy, that form of hysteric epilepsy so well described by Charcot, chronic alcoholism, etc. But we will reserve these for later study,

* So far as we have been able to learn, no accidents have occurred in the United States which could be referred to an inability to distinguish these color-signals. —TR.

when we will undertake the examination of the retina throughout its whole extent, in relation to its perception of colors.

We shall first consider colors, in the proper acceptation of the term, from a physical standpoint.

We divide colors into simple and compound, the latter being a combination of two or more simple colors. This combination, if made in certain determined proportions, produces white. We ought, therefore, in decomposing white, to be able, at will, to reproduce the various simple colors. We have the proof of this in the rainbow and the solar spectrum.

You all know how the solar spectrum is obtained; a beam of white light is let fall on a transparent prism, which refracts differently the various colors of which white light is composed.

In order to obtain brilliant spectral colors the light must be very intense and the spectrum must be produced in a dark room. Now, since this last condition is difficult to obtain in our dwellings, and we have not always the sun at our disposal, a portable apparatus has been constructed, which, when directed toward a luminous object, gives a spectrum in the interior of a tube. Such an instrument is called a *spectroscope.*

I show you one here. It consists of a metallic tube blackened on the interior and having at one end a diaphragm in which there is a slit that can be widened or narrowed at pleasure. The light, after passing through this slit, falls upon a prism, by which it is decomposed. An ocular fixed at the other end of the tube magnifies the spectrum and adapts the eye of the observer to the distance at which it is produced. By directing the spectroscope toward a white object we see a spectrum more or less intense according to the illumination of the object.

All the colors of the solar spectrum are simple, and cannot be further decomposed. If a green ray, for example, is allowed to fall on a prism it will be deviated in its proper direction, but not decomposed. If you look with the spectroscope at one color of the rainbow, you will not see a spectrum, but only a short band of the color examined.

As to the colors employed in the arts and industries, and such as are used in coloring papers and other materials, they are simply finely powdered colored matter; cinnabar, for example, and chromate of lead, sulphate of copper, and cobalt which is only very finely powdered glass of that color, etc.

All these materials, even the transparent colored bodies (liquids, glasses, etc.) color by *absorption*. They absorb certain rays of the white solar light which falls on them; the other rays pass through the body and constitute, by their mixture, the color peculiar to that body. The opaque colored bodies absorb, also, certain of the solar rays, and that which gives color to the body is the rays which are reflected after having passed through a layer of greater or less thickness on the surface.

The coloring matters are, therefore, rarely pure colors, but in the majority of cases, only a mixture of colors, notwithstanding the resemblance they bear to the simple ones. Of this you can easily convince yourself; look at any colored surface through a prism or spectroscope, and you will see that the principal color of that surface is decomposed into a series of colors, the combination of which made the impression on the eye of but a single one.

Here is a paper which appears to you of a perfectly pure red; that is, it appears to you exactly like the red of the spectrum or rainbow. It contains, as you can easily convince yourselves, not only red and the shades of red, but also yellow, violet, and even green and blue. This green paper furnishes us a spectrum so complete that you would not be able to judge correctly of its color by simply looking at it through a prism.

All this is of no great importance as far as regards art and the industries, whose aim is to produce on the eye certain impressions, it matters not by what means. But for our examination of the condition of the perception of colors in a given eye it is not a matter of indifference whether we employ simple or complex colors.

If, for example, an eye cannot perceive red, there will be a

very different impression made by the pure red of the spectrum and an artificial red, which contains, moreover, a series of colors which the eye cannot perceive.

For exact experiments the spectral colors are always to be preferred. They allow of a rigorous examination, and one comparable throughout its extent. Unfortunately they are not easy to produce or manipulate, because, in order to have the colors of sufficient intensity, we must have a very bright sun-light, a dark chamber, a heliostat, and a spectral apparatus; in a word, we must have conditions which we can seldom command in the routine of practice. Another serious obstacle is the difficulty of combining the various colors of the spectrum, an indispensable condition for a thorough and satisfactory examination.

Colored materials are, on the other hand, found everywhere. They are easy of combination, and we can have them on surfaces of any desired dimensions. In order to make a rigorous examination, however, we should always have a spectral analysis of the color employed.

What would you say of a physiologist who would publish his experiments with a bitter substance without indicating its nature? "It produces," he says, "tetanic symptoms." Another can deny this result from his experiments with a substance likewise bitter. Both, however, are right, if the first has employed strychnine and the other quinine.

If you employ two colors of red, they may be very different in their bases, one containing much blue and the other a large proportion of yellow. In order to make the experiments with the colors uniform, account must be taken of the various elementary colors which the materials used reflect or transmit.

It is very easy and simple, however, to analyze any colored material. You have only to look at it through a spectral apparatus and you have its composition directly. A simple prism will suffice if we look through it at a small band of the color on a black or white ground.

Now, the question arises, how can the various colors be mixed? I will not describe the methods for combining the colors of the spectrum, which are very complicated and cannot be used in ordinary practice.* It is otherwise, however, with the mixing of colors used in the industries, and we shall limit ourselves to the consideration of these.

But you must bear in mind that we do not, like the painters, mix the colored *materials*, but the *light* reflected from them. They are very different things. When a painter mixes a number of colors the resulting color is not like that which we obtain by mixing the light reflected by these colors. He takes a certain blue and a certain yellow, for instance, to make a green. If you mix, on the contrary, the same blue and the same yellow light, as, for instance, by superposing the blue and yellow of two solar spectra, you obtain a rose color as the result. Of this you can easily convince yourself.

We have not two solar spectra at hand, but we have here an apparatus which allows us to mix the light reflected from colored materials. Here is a disc of pasteboard (Maxwell's disc). I have made on it two concentric circles. The inner circle has been painted by a mixture of blue and yellow, to which the name of green has been given. The external circle, however, has been painted half in blue and half in yellow.

If we turn this disc rapidly about its axis, by means of a clock-work, you will see that the inner circle remains green, as it was before, while the outer part gives you a luminous impression, resulting from the fusion of the two impressions coming from the blue and yellow. The result is a rose color, entirely distinct from the green at the centre.

In order to explain this phenomenon let us take two colored glasses, one blue, the other yellow. In superposing them and looking at the sun, or a white object, you see it colored green.

* You will find a description of these methods in Helmholtz's "Physiological Optics," p. 303, Paris edition.

But this color does not represent the result of an *addition*, but, on the contrary, of a *subtraction* of colors.

The blue glass absorbs all the rays of white light, *including the yellow*, except the blue and greenish. The greater part of the rays absorbed would pass through the yellow glass. This glass, on its part, will absorb nearly all the rays which would pass through the blue glass, especially the blue rays. What remains and comes to our eye is the color which has not been absorbed either by the blue or the yellow glass, and this color is green.

We have, therefore, not combined the blue and the yellow, but have, on the contrary, cut off from the light coming to us the blue and yellow rays, and see only that which is left.

It is the same in painting. We would find it exceedingly difficult to convince a painter that a mixture of the seven simple colors would produce white. And why? Because, in mixing the colors on his palette he never obtains white, but only a grayish purple.

You will see, on the other hand, that nothing is easier than to have white by mixing the light reflected from these various colors.

The direct proof that we have not made an *addition* of colors in superposing the two glasses is this: The yellow glass is evidently much clearer (that is, contains more light) than the blue; and moreover, the color (green) which we see through the blue and yellow glasses superposed is much darker than that of each glass taken separately, deeper even than the blue which we have from the superposition of two blue glasses; a convincing proof that the first combination absorbs more light than the second.

I shall not occupy time in describing all the numerous methods which we have for producing a true mixture of colors.* In order to effect this it is not necessary that the impressions be produced simultaneously, but since each of the impressions continues for a

* I have explained this fully in the "Traité Complet d'Ophthalmologie"—Wecker and Landolt, vol. i, p. 552.

certain time it suffices to let them follow each other at short intervals.

For this purpose we use a disc, on which can be placed as many colored sectors as we desire. This disc is mounted on an apparatus which gives it a rotation so rapid that the eye can no longer discern the various individual colors, but only perceives the resultant color from the combination of all.

In order to determine exactly the quantity of each of the colors which enter into the mixture, we employ circles of colored paper which are cut in one of their radii. In this manner one can be slipped under another to any extent desired, and the exposed portion measured by means of a protractor.

If it is desirable to compare the various combinations, it suffices to produce them by means of concentric colored circles of different diameters.

Our apparatus is capable of making 80 revolutions per second, but from 50 to 60 revolutions generally suffice.

A statement of these physical facts was necessary to a proper understanding of what is to follow; and we will pass now to the physiological part of the subject—to the theory of the perception of colors. The one that is most widely known is the theory of Young, further developed by Helmholtz. According to this theory the eye possesses three distinct kinds of nervous elements, each of which receives one of the three fundamental colors: red, green, and violet (or blue).

The first kind of these elements is excited in the highest degree by the red rays, but also somewhat by the green, and feebly by the violet.

The second kind is affected by the green rays, and at the same time by the red and violet.

Finally, the violet rays excite strongly the elements of the third species, which are also somewhat sensible to the action of green rays, and very slightly to the red.

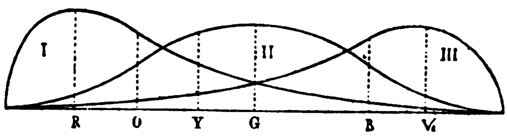
Each of these varieties excited separately transmits to the brain the impression of the fundamental color which is peculiar to it.

The intermediate colors are produced by the excitation of two or three of these groups of elements in different degrees.

Excited in equal degrees the three combined give us the impression of white (or gray). You can demonstrate this for yourself by the following experiment: I have adapted to the disc of Maxwell two concentric discs of different dimensions, the smaller composed of black and white, the other of red, violet and green. On rotating the instrument rapidly the same impression (gray) is produced by both.

You ask, probably, why I obtain gray and not white by a mixture of the fundamental colors. The answer to this question is very simple. White is only a relative expression. A paper which you would not hesitate to call white, when laid on the freshly-fallen snow will appear gray. The difference between white and gray is only one of degree of intensity. Gray is simply a dull white. Now, the colors of my mixture are not very bright nor intense, as compared with the colors of the solar spectrum. It is for this reason that they together produce, not a bright white, but a dull white or gray. In proportion as the luminous intensity of the colors of the mixture increases, the gray becomes lighter, and approaches more closely to what is commonly known as *white.*

FIG. 22.



The accompanying figure (22) represents, diagrammatically, this theory of Young-Helmholtz.

The curve I expresses the different degrees of excitation of the first element (the red) by each color of the spectrum. The maximum corresponds to the spectrum red.

Curves II and III have the same signification in relation to the second and third elements (green and violet).

If you wish to know in what various degrees these three nervous elements will be excited by any one color, draw a vertical line in the position of that color in the spectrum, in the yellow, for example, and see at what heights that line meets the different curves of excitation. In the case of yellow we see that the elements of that color excite with considerable intensity the element of red, the green a little less, and the violet very feebly.

I ought to add, perhaps, a word in regard to the complementary colors, and the manner in which they are explained by the theory of Young-Helmholtz. You are aware that when you have looked at a colored surface for some time and then turn the eyes to a white surface, in the place of the first color you see another; yellow if you have been looking at violet, blue if you have been looking at orange, and *vice versa*. These colors are called *complementary* one to the other.

This phenomena is explained by the Young-Helmholtz theory in the following manner:—

When you have looked at one color intently for a long time, the nervous elements of the retina especially impressed by that color become fatigued; in looking immediately afterward at a white ground the fatigued elements transmit a much less strong impression than those which have not been submitted to action. These latter are now excited by the other colors which comprise white light and give the impression of a color called *complementary*, because it is this one which, with the first one, constitutes white.

We are able, by mixing two complementary colors, to produce white.

We know, therefore, three different methods of producing white or gray.

1. The mixture of all the colors of the rainbow.
2. The mixture of three fundamental colors.

3. The mixture of two complementary colors. All the three methods can be carried out by means of the disc of Maxwell.

The theory of Young-Helmholtz, however ingenious it may be, is not entirely free from objections. While it explains most admirably some of the phenomena, especially the perception of colors, it does not at all explain, or in a very unsatisfactory manner, the phenomena of contrast. Having spoken of the theory of Young-Helmholtz, I cannot forbear to mention another newer theory, not less ingenious, which, particularly in regard to the perception of light, is very plausible indeed. This is the theory of Hering. I very much regret that the time allotted to these lectures will not allow me to enter into a consideration of this ingenious theory in detail. But for its full comprehension a series of experiments would be necessary which it is impossible to reproduce here, where we must limit ourselves to matters strictly practical. I advise you, however, to read the work of Hering, which he presented to the Academy of Vienna under the title "Zur Lehre vom Lichtsinne," and familiarize yourselves with this new and ingenious explanation of the sensation of light and colors.

We hasten on to our principal subject—the examination of the alterations of the perception of colors.

Derangements in the perception of colors are of two principal kinds. I. *Achromatopsia* (absence of the perception of colors). II. *Dyschromatopsia* (a difficulty in the perception of colors—diminution of perceptive power).

Achromatopsia and dyschromatopsia may be *total* or *partial*, according as the infirmity affects certain or all of the colors.

I. *Total achromatopsia* is a condition in which the individual has no perception of color, and only distinguishes differences in brightness. All objects are seen in about the same condition as in a photograph.

This affection is very rarely congenital, only a few cases of the kind having been accurately examined.

I have myself examined four cases of this character—young

men of eighteen to twenty years, who were born achromatopic. They all presented, aside from the achromatopsia, a considerable degree of amblyopia, photophobia and well-marked pallor of the optic nerve.

Total achromatopsia has been more frequently observed to develop itself in the course of cerebral affections or atrophy of the optic nerve. In these cases it is nearly always accompanied by a diminution of the other functions of the retina.

In the *partial achromatopsia* there is simply a lack of the perception of one or more of the fundamental colors. It is most frequently the red which is wanting, whence the name *anerythropes* given to persons so affected. Such was the case with Dalton, and hence it is frequently called *Daltonism*. But this word cannot be applied with exactness to the other numerous forms of the derangements in the perception of colors, nor even to all the forms of partial achromatopsia. Indeed, other elements besides the red may be affected; the *green*, the *blue* or the *violet* can be the lacking colors.

The symptoms of partial achromatopsia are easily inferred from what has been said above.

In this affection, that part of the solar spectrum corresponding to the color which is not perceived must necessarily appear dark.

If this part does not appear absolutely black it goes to prove that the color which is not perceived affects, in a feeble degree, the other nervous elements, which serve for the transmission or perception of other colors.

When the color that is not perceived is an extreme color of the spectrum, the spectrum appears shortened at one or the other of its extremities.

It has been proved that for the partial achromatope the maximum of brightness of the solar spectrum is frequently found, not in the yellow, as in the normal eye, but in another part of the spectrum.

Another characteristic of partial achromatopsia is that we can

produce, by means of two fundamental colors which are yet perceived, all the shades which the patient distinguishes, including white.

Thus, a partial achromatope who cannot distinguish red attributes to a certain combination of violet and green a grayish tint, which is produced for the normal eye by a mixture of white and black, or a mixture of all the three fundamental colors.

Finally, colored substances which contain a great deal of the color which is not perceived appear much darker than those which have less of it.

II. The second kind of derangement in the perception of colors —*dyschromatopsia*—is much more frequent than the first form.

Individuals of this class perceive all the colors, but all or a certain number do not make an impression as strong as on the normal eye. Consequently they have difficulty in recognizing certain colors; whence the name *dyschromatopsia* given to the affection. Dyschromatopsia, like achromatopsia, may be complete or partial; that is, it may affect the whole or only a portion of the colors.

Dyschromatopes see the solar spectrum of the same extent as the normal eye. They recognize perfectly the errors committed by the partial achromatopes. Only, colors closely allied are frequently confounded; violent is taken for blue, orange for bright red, pink for blue or bright violet, etc. As to the other bright shades, they are confounded with white, and the darker shades appear as gray or black.

In less pronounced cases the patients, under a functional examination, act as though of low intelligence, or as though not accustomed to distinguish the different shades of color, because, in looking attentively, they come sometimes to distinguish colors which they before confounded. On the contrary, the most pronounced cases call to mind the true achromatopsia. I am convinced, moreover, that many of the reported cases of achromatopsia are only those of dyschromatopsia not fully investigated.

For such an examination much more patience and precaution are necessary than one would suppose.

Indeed, the perception of colors is influenced by a great number of circumstances.

Strict account should be taken of the *intensity* and *extent of the color*, the *ground* on which it is seen, and the *general illumination*. If the influence of a single one of these factors is disregarded, achromatopsia can be found in all eyes, without exception.

Here, for example, is a card on which I have fastened small paper squares of bright colors, two millimeters apart, partly on a white ground and partly on a black ground.

Place this card at a distance of about ten meters and you will see each small square as a point of greater or less brightness, but without any coloration.

Increase the size of these squares, or what amounts to the same thing, diminish their distance from the eye, and you will find them, successively, to assume their proper color, distinguishing first the orange, then the yellow, bright green, red, blue, and finally the violet.

You should bear in mind another very important fact, namely, that the larger number of colors is better recognized on a black than on a white ground. At a distance some colors appear black on a white ground, such as red, blue and violet; at the same distance, on the other hand, they are easily recognized on a black ground.

Colored grounds bring out most distinctly their complementary colors; on a red ground, for example, green comes out with greater distinctness than on any other. Therefore, in the examination of the perception of colors, we should never use a colored ground, but a black one.

But the perception of color is most influenced by the intensity of the color and that of the general illumination. You know that in twilight colors become more and more indistinct and finally

disappear; the violet vanishing first, then green, yellow, and finally red and blue.

In the night we recognize the forms of objects by the differences in brightness, but we do not distinguish their color.

In order to study the influence of the intensity of colors on the facility of their perception we have only to combine them with black on the rotating disc of Maxwell, and we instantly see what is the minimum quantity which each color requires in order to be recognized. A very considerable proportion is sometimes necessary, often 10° for 360° of mixing.

All these facts prove to us that the normal eye itself is found in a state of dyschromatopsia, or even achromatopsia, as regards colors of small extent of surface, lessened intensity and insufficiently illuminated.

In other words, dyschromatopsia is frequently only an exaggeration of a defect of the normal eye. Between the normal eye and the achromatopic eye there are numerous degrees of defects in perception of colors, passing into each other by gradual and imperceptible shades. The difference between them is only one of degree.

This fact is not commonly known. It is the result, in part, of the observations which I have made on healthy and diseased eyes, which have also led me to other important results.

It has always been thought that the peripheral parts of the retina were achromatopic. This opinion was based on the fact, which was true, that the pieces of colored papers, seen under an angle of 70° or 80° appear colorless, and that in order to be recognized they must be approached more or less to the point of fixation.

But I have shown that it is only necessary to increase sufficiently their intensity, or their illumination, in order that all the colors may be recognized, up to the very periphery of the field of vision.

From this we derive most important indications for the

examination of the perception of colors, and you see that it is indispensable in this examination to take account not only of the composition of the colors which we use, but also of their extent, intensity and general illumination.

We will now consider the principal methods which are used in investigating the faulty perception of colors.

It evidently is not sufficient to show a patient a series of colors and ask him to designate them, nor to make him point out the different parts of the solar spectrum.

A partial achromatope may be able to call by their names all the various colors, which he can no longer see, as we do; he distinguishes them, it may be by a difference in their brightness, or by other indications which education has taught him.

We first place before the patient a series of colors in order to find the kind of defect present. We must have for this purpose a large number of different shades. The series which I use is composed of 350 different specimens.

We ask the individual under examination to choose from this number those which appear to him to have the same color, an operation which it takes the normal eye only a few minutes to accomplish.

A dyschromatope will find great difficulty in assorting them, and will confound the different shades of allied colors.

A partial achromatope will make yet greater errors, and will place green, for example, by the side of red, blue by yellow, etc.

This will tell you the colors to which you should pay particular attention in your examination.

Holmgren and others have proposed for this examination samples of colored wool, which are exceedingly well adapted for this kind of examination. To facilitate the examination, we place, as proposed by Holmgren, one of the samples before the patient and ask him to select from the others those which seem to him to be most like it, and pile them together. Holmgren begins by giving him a sample of green, bright and pure. The examination

is continued until he has arranged all the samples in piles which are to him of the same color.*

An achromatope will place samples of rose, gray and red together.

Then a sample of purple is placed before him. If in the first examination it is found that he has a defect in the perception of colors, but makes no mistake in respect to purple, he is only dyschromatopic. If, on the other hand, he adds the blue and violet, or either one, to the purple, he is achromatopic for *red*. If he confound the purple with green or gray, or both, he is achromatopic for *green*. If he adds red or orange to the purple he is achromatopic for *violet* or *blue*.

A sample of bright red is next given him. If achromatopic for red he will add as identical colors shades of green and brown which appear deeper to the normal eye than the red in question.

If achromatopic for green he will add shades of green and brown, which appear brighter to the normal eye than the red.

A method for the diagnosis of achromatopsia analogous to this has been proposed by Daae. For this purpose he employs a card containing the samples of colored wool arranged especially for the diagnosis of achromatopsia for red and green.

The table is composed of ten horizontal series of colors, each series being composed of seven colors represented by woollen threads. In a certain number of the series the colors are placed in the order of their intensity (saturation). These series correspond to numbers III (purple), VII (green), IX (red). The other lines do not enclose colors of the same order; that is, there is a variety of colors. His manner of examination is as follows:—

He places the card in a position where it will be well illuminated

* A translation of Holmgren's admirable paper on "Color-blindness in its Relations to Accidents by Rail and Sea," will be found in the Report of the Smithsonian Institution for 1877. Dr. B. Joy Jeffries, of Boston, has also treated of the matter at some length, in a paper on the "Dangers of Color-blindness in Railroad Employés and Pilots," in the Ninth Annual Report of the Massachusetts State Board of Health. The bibliography appended to this paper is the most complete that has yet been published.—Tr.

by daylight, and tells the patient that certain of the horizontal lines contain colors of the same tone, but of different degrees of saturation, ranging from the deep to the light, and asks him if the colors in the first series are of the same tone. When he has made his answer he is asked in regard to the second series, and so on until the whole is examined. If he recognizes all the colors, with their gradations in saturation, he is not achromatopic.

If he distinguishes neither the lines which contain only a single color, nor the others, his perception of colors has not been thoroughly examined. In such a case the trial must be begun again and repeated frequently, until a definite result is obtained.

If he says that one series which contains different colors contains only different shades of the same color, he is achromatopic.

In order to study, thoroughly, the nature of the achromatopsia it is important to show to the patient a solar spectrum. Is this seen in its normal extent? or does it appear shortened at one of its extremities? Is it, in some portions, obscured? Is the maximum of brightness at the same place as with the normal eye? These are some of the questions which you must decide whether the eye under examination is partially achromatopic or not.

In order to be more sure you can produce on the rotating disc of Maxwell a mixture of *two fundamental colors* which make on the eye the same impression as a mixture of black and white. If such are not to be found then you may know that the eye is not affected with achromatopsia.

The method which I employ for the determination of the perception of colors rests on exactly the same principle as the other methods of examining the functions of the eye.

As in determining the visual acuteness we endeavor to find the smallest retinal image which it can distinguish, and in determining the perception of light we find the minimum quantity of light which makes a luminous impression, so for the perception of colors I find the minimum of colored light necessary to produce the sensation of that color, and I express this minimum by a number.

To find this minimum of colored light I employ a method similar to that which is used in the determination of the perception of light, that is to say, I diminish gradually the intensity of the color. Now, to diminish the intensity of a color, be it white or colored, is the same as adding black to it. For this purpose I employ a modified disc of Maxwell.

The apparatus of Maxwell consists of a clockwork which sets in rapid rotation discs of colored paper, inserted one under the other so as to leave part of each exposed. These discs make fifty revolutions a second, and the sectors of colors succeed each other so rapidly that their retinal images can no longer be distinguished as separate colors, but make on the eye the impression of the color of the mixture of all.

In 1875 I proposed, under the name of "the method of minimum intensities," a procedure which consists in superposing on the apparatus of Maxwell a black disc and a disc of colored paper. By varying the surface of the colored section we can express in degrees the quantity of color which enters into the mixture.

But it might be objected that the black of our blackest paper is not an absolute black, and, indeed, the most intense black which we can produce by means of dyes is far from absolute black.

To do away with this defect I have devised the following modification of this procedure. The spring which sets the axle of the apparatus in motion is enclosed in the bottom of a deep box lined throughout with black velvet. All the light which enters this box being absorbed, the interior represents, very perfectly, an absolute black. The anterior part is pierced by a relatively small circular overture. The anterior extremity of the axle is just in the centre of this opening. If a section of color is fixed on this end and the apparatus put in motion the color becomes mixed with the black of the box.

To obtain, at the same time, many degrees of intensity of color, I mount on the apparatus a piece of colored paper composed of

five sectors, which diminish in size from the centre to the periphery, and which, in turning around the axis, describe five colored circles of intensities decreasing from the centre.

We have selected the sectors of such a size that the smallest mixed with the black describes a circle which is just at the limit which the normal eye can perceive; the second is twice the size of the first, and therefore corresponds to a color perception equal to one-half of the normal; the third is equal to one-fourth of the normal, and so on to $\frac{1}{16}$.

In experimenting with this apparatus I do not allow the individual under examination to see the five colored rings at the same time. To prevent this the circular opening in the box is covered by a diaphragm, pierced by five openings, which are provided with covers of the same size. Each of the concentric colored circles corresponds to one of the openings in the diaphragm.

We put the apparatus in motion, all the openings in the diaphragm being closed; we then remove cover No. 1, and if the individual under examination sees the color, I estimate that his faculty for the perception of colors is normal, or $= 1$. If it is necessary to uncover No. 2 in order for the color to be distinguished the degree of the perceptibility will be $= \frac{1}{2}$, and so on to $\frac{1}{4}$, $\frac{1}{8}$ and $\frac{1}{16}$, according as it is necessary to open successively the apertures Nos. 3, 4 and 5. We can thus determine easily and rapidly the quantity of colored light which an eye under examination is capable of perceiving, and we are enabled to express the result obtained by a number.

It is evident that we are not obliged to limit ourselves to the five sectors which we have chosen for our determination. We can increase the number to any required extent. Moreover, since these questions have begun to be studied in ophthalmology, it has become easy to find everywhere colored papers of the same degree of saturation. We can therefore consider the color as constant.

It is also evident that we should take account here of the

general illumination, as we do in the determination of the acuteness of vision and the perception of light. To this end we unite to our chromatometer a small photometer on a primitive plan, which indicates at what distance from the window the apparatus must be placed in order to obtain exact results.

This photometer consists of a translucent card on which is drawn a black line. The card is approached to the window until the black line is seen by transmitted light.

This apparatus, which I have now used for a considerable time, is very simple and practical, and by it we can easily diagnose the different degrees of achromatopsia and dyschromatopsia.

LECTURE XIV.

INDIRECT VISION AND THE VISUAL FIELD.

GENTLEMEN:—The functions of the eye which we have been considering in the preceding lectures, *visual acuteness, refraction, and perception of colors*, have all relation to DIRECT vision; in other words, we have examined only the functions of the *macula lutea*.

But, as the retina is extended much beyond the macula, our vision is far from being limited to the point of fixation. On the contrary, it embraces a large extent at the periphery, in which objects are seen indirectly, and this is called the *Visual Field*.

The field of vision is, therefore, the space throughout which the eye is able to see while its visual axis is directed to a certain fixed point. And as we call *direct vision* that which pertains to the macula, that which belongs to the rest of the retina is called *indirect* or *peripheral vision*.

We shall occupy ourselves to-day with the consideration of indirect vision and the limits of the visual field.

Indirect vision, although it may be very indistinct and imperfect in comparison with central vision, is, however, not less important than the latter. Without peripheric vision we would be in the condition of a man looking through a long, narrow tube which would allow of his seeing nothing but the object to which the axis of vision was directed. It would be impossible for him to see objects to one side without an incessant turning of the head. Imagine the great inconvenience we should experience in looking about us with such a state of vision, that is, with a visual field restricted to central vision!

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We know that without looking directly at the earth we can walk with perfect security over the most unequal ground, and avoid obstacles as they present themselves in our pathway. This would not be possible without the integrity of the upper portion of our retinæ, which corresponds to the lower part of the field of vision.

Again, it is the functional integrity of this part of the retina which permits a player on the piano to fix his gaze directly on the music he is playing, his indirect vision allowing him to direct the movements of his hands. If you will try to walk, or play the piano with a screen placed horizontally below the eyes, you will be speedily convinced of the very important service indirect vision renders us.

The movements which a leader of an orchestra makes with his *baton* are not, for this reason, as superfluous as would at first sight appear. The musicians, although they cannot turn their eyes from the notes, perceive, as a shadow, by means of their peripheric vision, every movement of their leader.

It would be easy to multiply examples, since all our occupations, all our movements in the streets and in our houses would be difficult in the extreme if we did not possess this indirect vision. It is this, in a word, which enables us to avoid those things which approach or menace us from all sides.

The pathology of indirect vision is of so much importance that we have reserved its consideration for a special lecture.

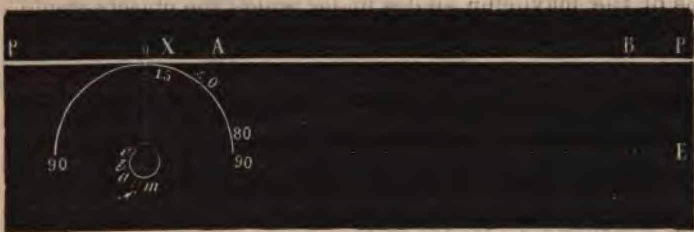
We should, however, in the first place, know how to examine the field of vision in regard, first, to its *limits*, and, second, to its *functions*.

We shall first study the method for measuring the extent of the field of vision.

It has been thought that this could be accomplished by causing the individual to fix a point on a blackboard and marking on the board the limits at which the eye could distinguish a white object gradually removed from the central point of fixation. This method, however, is very *insufficient* and *inexact*.

To convince yourself of its *insufficiency*, fix with one eye the index finger of the left hand, and make movements at the same time with the right hand at an angle of gradually increasing size with the visual line. You will then see that on the outer side as well as at the lower and outer quarter of the visual field, the eye can distinguish movements of the hand at an angle of 90 degrees and over. The limits of these parts of the visual field could not, therefore, be determined by means of a plane, since the rays coming from peripheral objects, falling in the eye perpendicular to the visual line, are necessarily parallel to the plane, and cannot, consequently, emanate from it.

FIG. 23.



Examine Fig. 23. Let PP be the section of a plane on which the visual field is to be determined. The luminous ray E*e*, which falls on the eye under an angle of 90° with the visual line, cannot come from the plane PP, since it is parallel to it.

But, even if it were possible to circumscribe the visual field on a plane, this method would yet be *inexact*. We do not wish simply to determine the limits of the field of vision, but also the functions of the eccentric portions of the retina. For this purpose we use test objects analogous to those which we employ for central vision. Now, it is evident that in moving either the letters of the test types or colored squares along a plane we examine the different portions of the retina under entirely different conditions; the object is further from the retina in proportion as it is removed from the point of fixation. Thus, supposing the eye to be 30 centimeters from the board, one part (a), situated at 40

degrees from the macula (m) is 39 cm. (aA) removed from the object, and a part b, situated at 80 degrees from the macula, is found at a distance of 173 centimeters (bB).

It is only up to a distance of 45 degrees that the differences in the distance can be practically neglected; beyond this they increase in such a proportion that all comparison between direct and indirect vision really becomes impossible.

In order to examine the visual field throughout the whole of its extent, and under such conditions as are comparable for all points of the retina, it is evident that the eye must be placed in the centre of a sphere one of whose poles it fixes.

The limits of the visual field would then be determined by means of the maximum angles under which the objects would yet be distinguished, and the functions of indirect vision would be examined by moving objects on the internal surface of this sphere. This method is the only rational one, because the sphere allows us to determine the visual field up to its extremest limits, and moreover, the test objects are always at the same distance from the various parts of the retina under examination.

Now, a sphere can be obtained in a variety of ways. The most practical form, however, is that found in the *perimeter*, which Aubert was the first to use, and to which we have given the following form (Fig. 24):—

It consists essentially of an arc of a circle of the value of a semi-circumference, which, in turning about its apex, describes in space a hemisphere, at the centre of which is found the eye under examination.

This arc of the circle is represented by P in the figure, and its apex is supported by a column (A). In front of this first support, and fixed on the same base, is a second upright (B), of such a height that its upper portion, which is bent slightly backward, is just at the level of the lower orbital wall when the eye is at the center (C) of the arc. In order to fulfill this last condition this shank (C) must rest against the lower edge of the corresponding orbit. For

fixing the chin there is a cross piece of wood which glides up and down on the upright (B). This piece has two depressions, one on each side of C, for the chin to rest in.

If you are examining the left eye, for example, the chin, in order that the head be held erect, must rest in the depression on the right side. The cross piece should, therefore, be sufficiently elevated, so that when the head is resting on it the lower portion

FIG. 24.

of the left orbit should be at the level of the top of the shank, and in contact with it. In this way the optical centre of the eye is at the centre (C) of the hemisphere which the arc describes when turning about its axis.

The arc is divided into degrees, starting from 0°, which marks its apex, up to 90° on both sides. The divisions are marked on the outside of the arc.

The inclination of the arc to the meridian is read off on a small

dial which is placed vertically on the outside of the arc at its apex, having the apex as a centre. Around the face of this dial moves a pointer (I) parallel to the plane of the arc and turning with it.

The inner surface of the arc is blackened, save at the point of fixation. The object which is used to examine the indirect vision, white or colored paper, figures or letters, can be moved by forceps, or can be placed in a small frame which glides along the arc, and whose posterior arm indicates the corresponding degree on the outer side.

For delicate measurements in the neighborhood of the yellow spot the divisions, up to about 20° from the centre, are in half degrees. It was by means of this division that I made my determinations of the distance between the macula and optic nerve. For the determination of the limits of the visual field we proceed as follows:—

The head being fixed as indicated previously, and the eye to be examined being placed in the centre of the arc of the perimeter, we cover the other eye with a bandage rather than with the hand or a handkerchief, the thickness of which latter is likely to restrict somewhat the inner portion of the visual field.

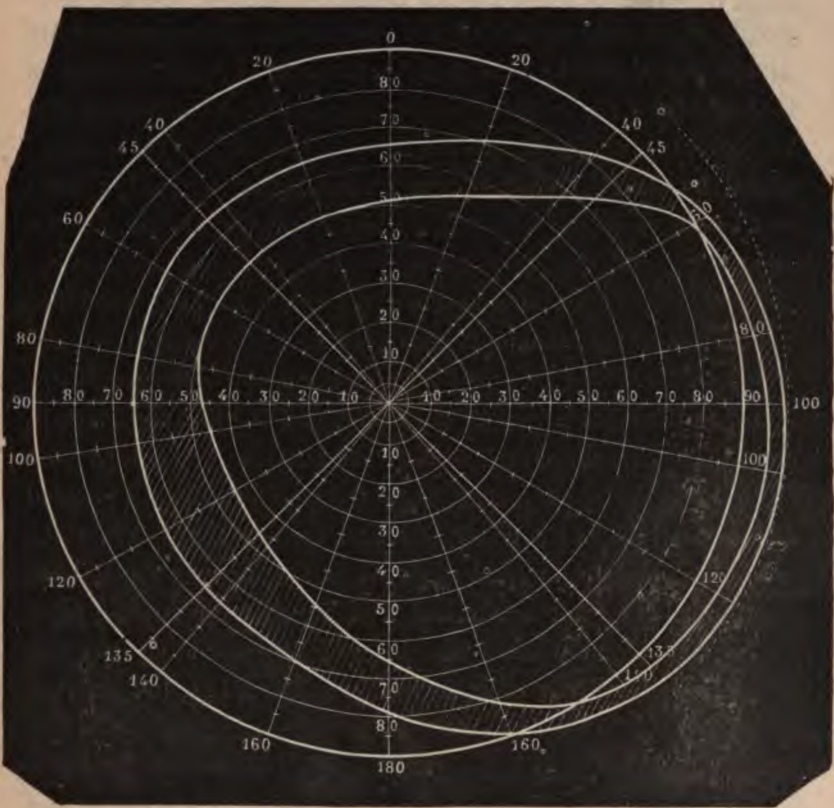
We then request the patient to fix accurately the white spot marked on the centre of the arc, while the examiner, placing himself behind the perimeter, controls with the greatest care the direction of the eye and checks its least movements from this position. Then, the arc of the perimeter being held in a certain plane, the horizontal, for example, the test object is advanced from the periphery toward the apex, up to the point where it is recognized by the eye under examination. This point marks the limit of the visual field for the corresponding meridian. The examination being completed for one side of the arc, it is made in the same manner for the other.

Another plane is then taken, and the limit found at which an object is recognized when approached from the periphery toward the centre.

Ordinarily it is sufficient to examine only four meridians, the horizontal, the vertical and two intermediate, that is to say, a meridian for every 45 degrees.

The field of vision, thus determined, is transcribed on a diagram which represents the projection of a sphere on a plane surface

FIG. 25.



(*polar equidistant* projection) (Fig. 25). This diagram consists of a series of concentric circles cut by numerous radii, or rather diameters. The centre, zero, of the figure corresponds to the point of fixation, and the diameters to the different planes of the arc, or the meridians in which measurements have been made. At the extremity of each diameter is a number indicating the

degree of inclination of the corresponding meridian to the vertical; this division corresponds necessarily to that of the dial of the perimeter. The radii are themselves divided, counting from the centre, into equal parts, each part corresponding to 5° of the divisions on the arc; 0° representing the apex and 90° its extremity.

It is easy, in this manner, to represent on the diagram the results of an examination of the visual field. Two diagrams are usually placed side by side on the same sheet of paper, the one on the right hand representing the right eye, the left one the left eye. The external part of the visual field of the right eye is represented by the right side of the corresponding figure, the inner part by the left side; the reverse is the case, of course, for the other eye.

Suppose we are examining the right eye; we have examined the horizontal meridian, and found 85° on the outer side and 40° on the inner. We now find on the horizontal diameter, in the figure on the right hand, the division numbered 85° and mark it, and at the same time mark 40° on the left side. We then pass on to the intermediate meridians, to the one, for example, inclined 45° to the right on the upper part, and find on the diagram the corresponding diameter, and mark on it the degrees which have been found to limit the visual field in that direction. After having found and marked the degrees corresponding to each meridian we have only to unite, by a continuous line, the different points marked, to have the limits in all directions of the field of vision.

The inner curve of Figure 25 was obtained in this manner, and marks the extent of the visual field of my right eye when I fix accurately the apex of the arc (the centre of the figure). The extent of my visual field is as follows: outward 95°; upward 53°; inward 47°; downward 65°.

We thus see that the visual field is far from being circular, as one would suppose it, *a priori*, to be. It has its greatest extent

outward and at the lower external portion. The upper, and particularly the inner part are much more restricted.

We would be likely to attribute the limitation upward and inward to the presence of the cranial bones; and the superior edge of the orbit and bridge of the nose do interpose, indeed, a considerable obstacle to indirect vision.

The influence of the nose, however, can be eliminated by a slight rotation of the chin-support around its axis. In order to avoid all obstacles a point must be fixed for each meridian at 30° in the opposite direction to that under measurement. Under these conditions a curve is obtained as represented in the outer curve in the figure. But you see that in spite of all these precautions the field of vision yet remains restricted in the directions indicated.

This is due, in part, to the fact that the retina does not come so far forward on the outer as on the inner side of the globe, but the principal reason is that the outer part is less used than the inner. When we see (in indirect vision) to the left side, it is not with the external part of the retina of the right eye, but with the internal portion of the retina of the left eye, while the external part of the left eye is replaced by the inner part of the right eye. It follows that the functions of the parts less exercised are less developed, and that the visual field corresponding to these parts is less extended. This explanation, which I gave in 1872, has been recently confirmed by the experiments of Donders.

After having thus determined the *limits* of indirect vision, we must examine its *functions*, following the same principles which have guided us in the determination of direct vision.

The *acuteness of vision of the peripheral parts of the retina* has only recently been made the subject of research. When in Utrecht I made examinations of this kind with my friend Ito. We used, as test objects, two small black squares on a white ground, identical with those in Nos. I, II, III, IV, in Figure 26.

These were introduced successively in the frame of my perimeter, and we determined, separately, the degree at which the two

squares could be distinguished from each other. It was astonishing to see to what a short distance it was necessary to approach

FIG. 26.

these objects toward the centre in order that the two points be distinguished from each other.

The diagram (Fig. 27) indicates for my right eye the limits of the different visual fields for each size of the object; the figures nearest the centre of the diagram correspond to size No. IV, the

FIG. 27.

second to No. III, the third to No. II, and the external one to No. I. These experiments show us that the visual acuteness is better developed in the upper, and upper and outer parts of the retina, while it is less developed in the lower and outer.

The *perception of colors* of the eccentric parts of the retina is

determined by introducing into the frame of the perimeter variously-colored papers, and bringing them from the periphery toward the centre until that color is recognized. It has been found that the curves corresponding to the various colors differ notably from the limits of the general field of vision, that is from that of white light.

By using brilliantly-colored papers about four centimeters square, we have shown that at first the normal eye recognizes the movements of objects at the periphery a long time before it can distinguish their colors.

Starting from the periphery, blue is the color which is first recognized; its visual field extends nearly up to the limit of the general visual field. After that comes bright yellow, which appears, at first, as white. Orange appears for a long time as yellow before it is recognized in its true tint.

Red, which follows next in order, appears first as almost black, afterward as deep brown, brown, and finally as red. The field of green is still more limited than that of red. At the periphery it generally makes an impression of white or gray; nearer the centre bright green appears yellow; deep green as grayish blue. It is only afterward that it is recognized as green.

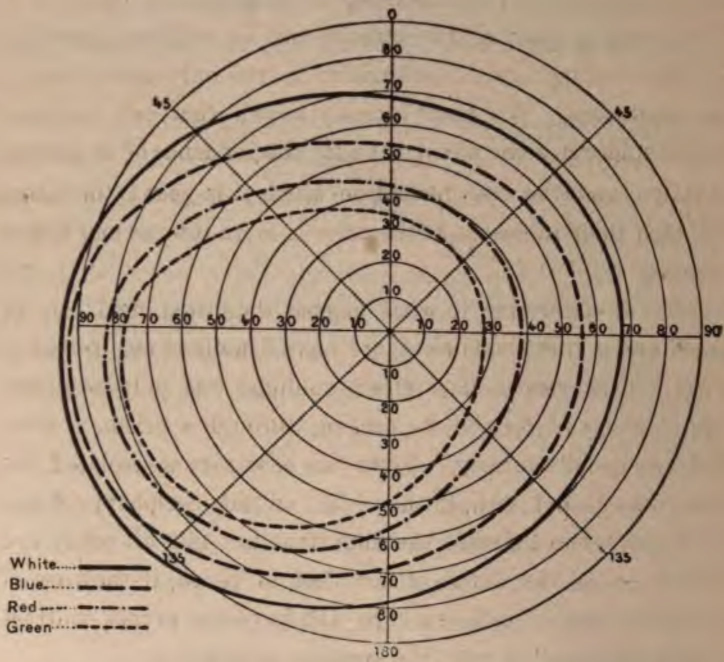
Violet for a long while gives the impression of blue, before it is distinguished as violet; its limits are the more extended the purer the shade.

In practice it suffices to measure the visual fields of green, red and blue, because, as we have shown, the field of yellow differs generally but little from the blue, and that of orange is always found between the limits of yellow and red; violet is not a good color for practical experiments.

You will see in the diagram (Fig. 28) the curves which mark the limits of the visual fields of the three colors. These are the mean limits which I have deduced from the examination of a number of normal eyes. All that part comprised between the centre (point of fixation) and each curve indicates the color of a

square; the rest of the retina could not distinguish it (under the conditions indicated previously).

FIG. 28.



It is a great mistake to suppose that the perception of each color throughout the whole extent of the retina is as vivid as at the centre. There is a great difference in the appearance of the same color, according as it is viewed directly or at one side. The curves only indicate the limits of the visual field where the individual under examination gives the color its true name, but it is then far from being pronounced. It only becomes of its deepest intensity in direct vision.

It was for a long time thought, and you will find it stated in many text-books on ophthalmology and physiological optics, that the periphery of the retina is achromatopic. They have even gone further, and founded on this supposition a theory of the physiology of the retina. Since in the parts nearer the macula

the cones predominate, while they are almost completely wanting at the periphery, it was concluded, without hesitation, that the cones were designed for the perception of colors, while the rods were only charged with the quantitative perception of light.

What we have found in our experiments with colored papers of a given size and moderate illumination is true only under certain special conditions. We have already shown that our limits of colors can undergo some changes under the influence of an altered illumination, and the background on which it is seen; the visual field of each color increases as the color is more intense and better illuminated.

In order to determine to what degree the visual field can be increased under these conditions, we have examined our retina in a perfectly dark room. The direct sunlight was only admitted through a slit, and formed, by passing through a prism, a solar spectrum of great intensity. From this spectrum we isolated the different colors, and letting them fall on the periphery of our retina we have demonstrated the important fact that all colors are recognized up to the limits of the field of vision, if they are of sufficient intensity, of sufficient size, and have the proper contrast with the background or with the general illumination.

It results from this discovery that the supposed special function of the rods and cones has no existence, and that, in each examination of this character we should indicate, exactly, the nature of the light employed, its degree of saturation, its intensity, its size, as well as the character of the ground on which it appears, and the illumination of the room in which the experiment is made.

It is evident that in practice we have never need of colors of maximum intensity. Colored papers about four centimeters square are the best for the examination of pathological cases, provided we always indicate the degree of illumination, the nature of the color, and its distance from the eye. The results thus obtained will then be directly comparable with those which the healthy eye furnishes under the same conditions.

If you compare the functions of indirect vision with those of central vision under the influence of a diminution of illumination, you will find a certain analogy between the increasing indistinctness with which the forms and colors of objects are distinguished when they are removed from the point of fixation toward the periphery, and the difficulty with which they are seen directly when the illumination is enfeebled. It is especially since I have shown that the imperfectness in the perception of colors in indirect vision was simply the result of lack of luminous intensity, that attempts have been made to explain all differences which exist between direct and indirect vision by the relative weakness of illumination of the peripheral part of the retina.

We would say, that between the functions of direct and indirect vision there is no difference of kind, but only of degree, the eccentric parts of the retina having need, to respond to excitations of the same nature, of a greater quantity of the excitant. In other words, it is thought that the perception of light, the perception of colors, and the perception of forms (visual acuteness) diminish in equal proportion, be it through a diminution of illumination, or a gradual removal of the object from the point of fixation.

As regards the *perception of light* in the different portions of the retina, I determined, by means of a plan which I have explained elsewhere,* the minimum quantity of light necessary to produce a luminous impression on the different portions of the retina, by removing it gradually from the centre toward the periphery.

I have found that the perception of light remains almost exactly the same throughout the whole extent of the retina.

After I had determined the visual acuteness and the perception of colors in an eccentric portion of the retina, and afterward diminished the illumination just sufficiently to make the central acuteness of vision equal to that previously determined for that particular eccentric part, with that diminished illumination I deter-

* Wecker and Landolt—Traité complet. d'ophthalmologie

mined the perception of colors for central vision. These experiments demonstrated that the two sensibilities, at the centre, and at the peripheral portions of the retina, do not vary in the same proportions. For an equal visual acuteness, the perception of colors is much more acute at the periphery than at the centre, or reciprocally, for an equality in the perception of colors, the acuteness of vision is much better in direct vision than in indirect vision. The acuteness of vision, therefore, diminishes much more rapidly in removing the object from the point of fixation, than in diminishing the illumination of the object.

My experiments have proven that there is an essential difference between the functions of the centre and those of the eccentric portions of the retina. While the perception of light is nearly the same throughout the entire sensitive portion of the retina, the perception of colors is much less vivid in the eccentric portions than at the centre, and diminishes progressively in proportion as they approach the periphery of the visual field. The visual acuteness (perception of form) finally diminishes more rapidly toward the periphery than the perception of colors.

Take, for example, my right eye, with all three functions at the centre $= 1$. The perception of light at a part 30° from the centre will be also $= 1$, the perception of colors $= \frac{1}{14}$, and the visual acuteness $= \frac{1}{48}$.

Although these figures have only a relative value, the fact that of the three functions the perception of light remains the most constant, while the perception of colors and the visual acuteness diminish rapidly toward the periphery of the retina, the latter more than the former, is incontestably established by my experiments.

The fact is of the greatest importance for the explanation of the different functions of the retina. It proves that these three functions are entirely distinct from each other and cannot be reduced to a single one, as we would be tempted to believe. On the contrary, we are justified in believing that there are different

nervous elements, distributed in a different manner throughout the extent of the retina, presiding over the three different functions of the organ of vision.

We will now return to the application of perimetry to practical ophthalmology.

After having determined the limits of the field of vision, we must take care to find if there exist any defects or *scotomata* within these limits. This examination will not, I think, offer any difficulty, and it suffices to abstract, for the different meridians, the limits between which the objects or colors distinguished most peripherally disappear.

There is one of these defects which is physiological, and of the existence of which you should be aware; it is the one which corresponds to the entrance of the optic nerve, and which is known under the name of the *punctum cæcum* or *Mariotte's spot*. You are aware that the optic papilla is to the inner side and a little above the macula; you should find, consequently, a corresponding defect in the visual field, outward and slightly below the point of fixation; in fact, it is generally found 15° outward and 3° below the fixation point, in the emmetropic eye.

In Fig. 23, for example, which represents the right eye, m is the macula, x corresponds to the optic nerve, and X to the position of the spot of Mariotte on the plane PP. It is 15° from the point of fixation 0. From a large number of experiments which I have made on this subject, and from those made by Dobrowolsky, this interval is greater in hypermetropes and smaller in myopes.

On a plane situated at thirty centimeters from the cornea you first encounter it at about 8 cm. from the point of fixation. You can describe its limits by moving in different directions on the plane the point of a pencil, and marking the places where the point begins to disappear. I have marked out in this manner, a great number of times, my blind spot, and measured its size. It is oval in form, with its greatest diameter vertical. For my right eye, and at a distance of thirty-five centimeters from the cornea

to the plane of projection, its mean height is fifty-two millimeters, and its breadth forty-four mm. This experiment is easy to make, although the limits in certain directions are difficult to mark with precision, on account of the emergence of the retinal vessels, the trunks of which stop the light.

Moreover, in the interior of the visual field there are physiological defects, due to the presence of vessels at the place where the image of the point under consideration should fall.

LECTURE XV.

THE VISUAL FIELD (CONTINUED).

GENTLEMEN:—Now that we have learned how to examine the limits and functions of indirect vision, it remains to make an application of this knowledge to the numerous pathological cases in which it is liable to be affected. We shall speak of it briefly, bringing forward only the more important facts, since there is scarcely a lesion of the interior of the eye which is not accompanied by perimetric symptoms; and moreover, all the diseases of the brain and spinal cord which are manifested by symptoms in the organ of vision commence by some abnormality in the form and functions of the visual field.

Among the diseases purely ocular we cite, in the first place, glaucoma. One of the first symptoms of this disease is a restriction of the visual field, which is limited to one side, and particularly to the inner and upper portion. This symptom is so characteristic that in doubtful cases it is especially depended on in making a diagnosis, though there are exceptions where the limitations are found outward and a little below.

Hemorrhages into the tissue of the retina necessarily cause a complete abolition of vision in the parts affected. This is manifested by a fixed scotoma in the visual field. The perimeter becomes, in such a case, a valuable means, more delicate than the ophthalmoscope even, for following the progress of the trouble, as is directly indicated by the increase or diminution in the size of the scotoma. So long as the limits of the scotoma are indistinct and variable the morbid process is still in action.

Another very common affection is manifested by scotomata in

the visual field, and that is choroiditis disseminata, which rarely passes away without leaving some alteration in the retina. It manifests itself at first at the periphery, where the ophthalmoscope is frequently powerless to show us anything. Now, even at this early period, the perimetric examination shows its existence by the irregularity of the limits of the field of vision, or by the presence of peripheric scotomata.

The commencement of these scotomata is manifested particularly when the examination is made by means of objects which offer but little contrast to the black ground of the perimeter on which they are seen. Thus, for instance, when the examination is made by means of a gray or red paper, scotomata sometimes reveal themselves which are not perceptible when a white disk is used.

There is no affection of the retina whose progress cannot be traced in the field of vision. Detachment of the retina, for example, necessarily involves the loss of that part of the visual field corresponding to it. You have here the visual field of a detachment of the lower portion of the retina. It is restricted, as you see, above. This one, which is narrowed considerably throughout its whole extent, corresponds to a detachment extending around the optic nerve. It is in the form of a funnel, at the bottom of which is the optic nerve. As in the ophthalmoscopic image the papilla forms the centre of the detachment, so in the diagram, the spot of Mariotte forms the centre of the narrowed field of vision.

Frequently the diagnosis of a detachment of the retina is of very great importance, as in cataract, for instance, where it is desirable to know whether to undertake an operation for its relief or not. In this case an examination of the visual field is the only means we have of making a diagnosis. We can make this examination by causing the patient to fix a luminous point while we throw on the eye, by means of a small mirror, the light from a lamp. By varying the position of the mirror we can give to the light all desired directions, and thus examine the perception

of light throughout the entire extent of the retina. If the perception of light is preserved we know that there is no detachment or other serious disease of the fundus.

The importance of perimetry in detachment of the retina does not consist, moreover, solely in the diagnosis of this condition; it is of special importance in prognosis. If the restriction of the visual field is greater than the detachment as made out with the ophthalmoscope, this proves to us that a part of the retina situated beyond the visible detachment has already lost its sensibility; consequently we should expect a rapid progressive increase of the detachment. In the cases, on the contrary, where a part of the detached retina is still sensitive, the prognosis is more favorable. Sometimes, under the influence of appropriate treatment and an absolute quiet on the part of the patient, with seclusion in a dark room, the retina replaces itself and resumes its functions.

It is characteristic of the visual field of the detached retina that the various functional limits are found at the same place. The visual field of colors, which is normally, and in a large number of pathological conditions, nearly parallel to the external limits of the general visual field, is cut off short at the place where it enters the detachment.

A striking example of the correspondence between the ophthalmoscopic and perimetric signs is found in the following case, whose visual fields you see here. A foreign body had entered the eye, and lacerating the retina and choroid, had lodged in the sclerotic. A large extravasation of blood hid the lacerated parts, as well as the foreign body. At this period the first visual field was taken. It shows a deficiency similar in form to the extravasation, except that it is ragged. Some days after, the blood began to be absorbed and the relief to the retina adjacent was manifested immediately by a diminution of the scotoma.

Later, the greater part of the extravasation was separated from the point of lesion. We have, consequently, a scotoma which

corresponds to that, detached from the peripheral scotoma caused by the laceration. Finally, when all the blood was absorbed, this scotoma disappeared and there only remained the scotoma from the wound. We then permitted the patient to leave the clinic, certain that we had obtained all the amelioration possible in the case, since we could, evidently, not hope to reëstablish the function of the lacerated part of the retina.

All inflammations of the retina find their expressions in the field of vision, by affecting its form, limit and functions, but especially the relations which exist between central vision and peripheric vision on the one hand, and on the other, between the visual fields of the various colors and the limits of the field of vision in general. Thus, we see retinitis pigmentosa accompanied by a concentric restriction of all the functions of the retina, and this restriction approaches more and more toward the centre, the visual acuteness of which remains for a long time quite good, there being no scotomata, and no irregularities in the boundary of the visual field.

Syphilitic and Bright's retinitis, on the contrary, attack direct vision at the beginning, leaving the outer parts of the visual field for a long time intact. The perception of colors is altered in such a manner that the limits of the different colors are very indistinct, sometimes crossing and frequently changing their places.

Scotomata are hardly ever lacking in apoplexies, infiltrations and degenerations of the retina.

When the optic nerve takes part in morbid processes we find an increase in the size of Mariotte's blind spot, resulting from an exudation into the retinal tissue in the immediate vicinity of the optic papilla.

No doubt perimetry would throw some light on those cases of amblyopia without any known cause, and where the ophthalmoscope shows us nothing. It will be the same, I hope, in toxic and hysteric amblyopia, and amblyopia in consequence of great loss of blood and insufficient nutrition—diseases the nature of which is

very obscure. In these instances the perimetric phenomena have the same significance as in atrophy of the optic nerve.

We will call attention, in passing, to the central scotoma caused by an alteration at the macula with extension of the blind spot in posterior choroiditis, which is so frequently the cause of progressive myopia; the central scotoma which is produced by embolism of the central artery of the retina, hyperæmia or hemorrhage at the macula; the peculiar scotoma of toxic amblyopia—a central scotoma of small extent, *affecting frequently only the perception of red.*

But, independently of its utility in the diagnosis of diseases of the eye, properly speaking, the perimeter has yet another important application. You are aware of the great hopes that were raised by the discovery of the ophthalmoscope for the diagnosis of diseases of the brain by this instrument. You know, also, that these hopes have not been realized to the extent we had expected. The cause for this is easily explained. There are only about five different conditions of the optic nerve which are distinguishable by means of the ophthalmoscope, while it ought to reveal at least ten separate cerebral diseases (making abstraction of the infinite varieties of seat and extent). It is here that perimetry comes to the aid of the ophthalmoscope, and the two methods united have already considerably increased the number and value of the symptoms relative to cerebral diseases as manifested in the eye.

Thus, a concentric restriction of indirect vision, accompanied by a diminution of visual acuteness, indicates frequently a neuritis of the extra-bulbar portion of the optic nerve, of which the ophthalmoscope shows no trace. An atrophy of the nerve can follow this inflammation without our being able to observe at the fundus of the eye any signs of the neuritis.

The autopsy furnishes the proof of the diagnosis by showing a destruction of the extra-ocular nerve fibres, hypertrophy of the

connective tissue, and, as a principal cause, the existence of an encephalic affection.

The most frequent symptom which the ophthalmoscope shows us in these cases of cerebral disease is atrophy of the papilla. The white, flat papilla, with thin vessels, may be the result of various diseases of the nervous system and the encephalon, without the ophthalmoscope being able to indicate to us the special cause. In those frequent cases where the vision is not completely lost we can employ the perimeter with advantage.

Atrophy of the optic nerve from peripheral causes, that is, in consequence of an alteration of a part external to the chiasma, affects different parts and different functions of the retina in very various ways. The visual field can preserve a relatively large extent, in spite of the nearly complete obliteration of central vision. The limits are generally very irregular and present sinuosities. Sometimes a sector of the visual field is wanting. Now, in all these cases the prognosis depends solely on the perception of colors. If the visual field of all the colors is little altered, especially if its limits do not run parallel with the irregularities of the external limits of the general visual field, the prognosis is favorable, that is to say, we can expect some amelioration, or, at least, an arrest of the morbid process. If, on the other hand, the perception of colors occupies but a small portion of the visual field, if it follows all the sinuosities of the external limits, or if certain colors are totally lacking at the periphery, the prognosis is very bad, and we have to do with a progressive atrophy.

In such cases the visual field of colors is gradually narrowed; in the first place violet and green are recognized only at the point of fixation, and afterward disappear entirely; violet still appears for a certain time as bluish, but soon it becomes a deep gray; bright green makes the same impression as white or clear gray; deep green appears as deep gray. By and by red follows the two other colors; it passes through a state where it is recognized as brown and finally becomes black. Yellow and blue

persist for the longest time. But after a while yellow becomes white, and blue is the only color which the patient can distinguish up to the time when complete achromatopsia sets in and renders the prognosis the gloomiest possible.

This diminution of the visual field of colors and the disappearance of certain of them (as green and red) are found in alcoholism, where they accompany a most marked diminution of the visual acuteness. In these cases the external limits of the visual field can remain of considerable extent, but the alteration of the perception of colors renders the prognosis, in spite of this, exceedingly bad. We can, on the other hand, look for good effects from general treatment when the curves of colors are preserved proportionally to the general extent of the visual field.

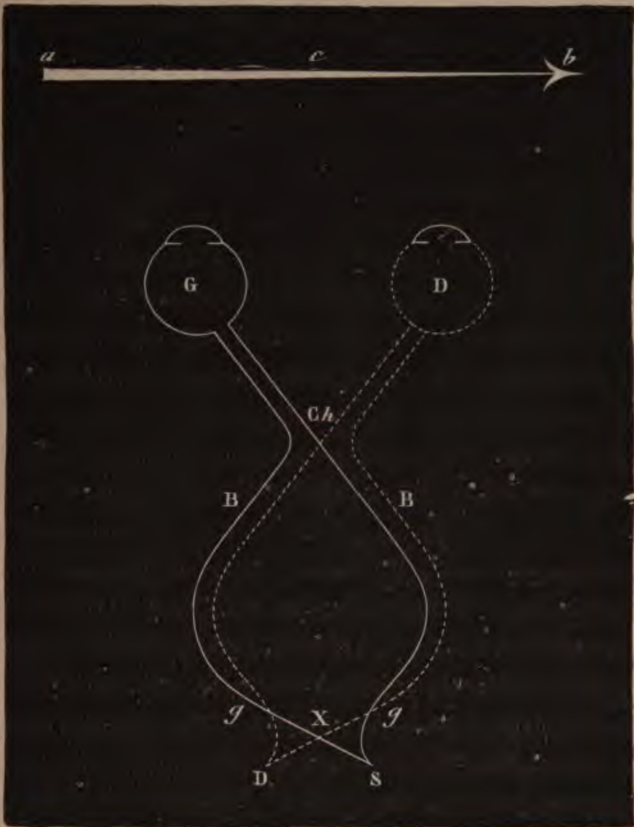
The alterations of the visual field in ataxia and in certain diseases of the spinal cord are of no less importance. A visual field very irregular in its general limits, as well as in its color limits, which cross in a confused manner, the existence of absolute scotomata or scotomota for certain colors, confirm the diagnosis and render the prognosis more or less grave, according to the degree of their development.

Outside of this series of diseases the perimeter furnishes us with important indications as to the location of certain cerebral troubles. Hemiopia, which consists in the lack of a corresponding part of the visual field in the two eyes, indicates a lesion in the optic tract on the side opposite to the part of the visual field which is lacking.

This is easily accounted for by the decussation of the optic nerves at the chiasma (Fig. 29). Of the nerve fibres of each optic tract one portion is directed, according to this theory, toward the opposite side, crossing at the chiasma, to go to the inner half of the corresponding retina; another portion goes, without crossing, to the external half of the same side. Now, a lesion of the right optic tract evidently destroys the sensibility of the right half of each retina, and consequently the left half of the visual field of

each eye, or the common visual field. Each eye, in fixing the object *ab*, will only see the part *cb*, the rays from which fall on

FIG. 29.



the sensitive part of the retina. Thus, individuals affected with hemiopia can see only the half of objects which they fix. There are cases where the loss of sensibility has not invaded the whole half of the retina. The defect of the visual field only takes in a similar part of the two eyes, as in the case I now show you. This is also called hemiopia, and is attributed to a lesion of the optic tract of the opposite side. In this case, however, it is incomplete.

It is characteristic of hemiopia that the abolition of the perception of colors is as clearly marked as that of the perception of light in general. The limits of the visual fields of colors follow the external limits only in the region of the sensitive parts of the retina. When they arrive at the limits of the hemiopia they are cut short off. This is easily explained, and it differentiates hemiopia from the other defects in the visual field.

A neoplasm having its seat in the anterior angle of the chiasma can alter the inner portion of the two optic tracts in such a manner as to abolish the functions of the inner parts of the two retinæ and destroy the external portion of the visual field; this is called *temporal hemiopia.*

As to *nasal hemiopia*, the loss of the external halves of the retinæ, if it exists, we have shown how it can be explained by the theory of semi-decussation (*Progrès Médicale*, 1875, No. 52).

Finally, it remains to cite certain peculiarities of the field of vision which we have been able to study in the service of M. Charcot at the Salpetriére. In certain cases of hemianæsthesia, hemiplegia and hemichorea we find, besides amblyopia of the eye of the paralyzed side, a concentric contraction of the visual field, with contraction for colors, and this without any ophthalmoscopic manifestations. These symptoms are not transient: they persist for years, and increase with the progress of the disease. The eye of the opposite side may remain intact.

These facts are of great importance. Similar alterations in the general sensibility, in hearing and smell, speak strongly in favor of the existence of a central encephalic focus. And, in fact, the autopsies of several similar cases, in which death came about by apoplexy, have shown regularly a lesion of the posterior portion of the optic thalamus and the neighboring parts. M. Charcot argues, from this, that a lesion is situated at the same place in the cases, exactly similar in their character, of hemianæsthesia and hysteric hemiplegia.

It has been thought up to the present time, however, that all lesions beyond the chiasma, all central lesions, could only produce hemiopia, in consequence of the incomplete crossing of the optic nerves in the chiasma. Amblyopia of a single eye, it was thought, could be brought about only by a unilateral neuritis. Now, in the cases of which we speak, the amblyopia or amaurosis unilateralis were evidently due to a central lesion. In order to explain this we must admit a common centre for the termination of the optic nerve fibres belonging to one eye, situated on the opposite side of the brain. In other words, the fact of a semi-decussation of the optic nerve fibres in the chiasma being incontestable, it is evident that the nerve fibres which do not cross at the chiasma, but form a part of the optic tract of the same side, must cross higher up, beyond the corpora geniculata, to come to the common centre of the nerve on that side, possibly in the neighborhood of the corpora quadrigemina anteriora. A glance at Fig. 29 will at once make this plain. G is the left eye. D the right eye. CH the chiasma where the optic nerve fibres corresponding to the inner part of each retina cross. BB the optic tracts. *gg* the corpora geniculata. X the crossing of the fibres which do not cross in the chiasma. D the termination in the brain of all the optic nerve fibres of the right eye. S termination in the brain of all the optic nerve fibres of the left eye.

This theory is much more plausible than that of the incomplete crossing, because it does not allow the optic nerve to form an exception to the rule which applies to all the cranial nerves which cross before arriving at their respective distributions.

Finally, leaving to anatomy and experimental physiology the explanation of the phenomena, it suffices for our present purpose to have pointed out a new ocular symptom, useful for localizing a cerebral trouble; that is, unilateral amblyopia with concentric and proportional restriction of the visual field, sometimes without and sometimes with a more or less complete white atrophy of

the optic disks, which indicates a lesion not far from the corpora quadrigemina and the posterior portion of the optic thalamus of the opposite side.

NOTE.—We have thought it of interest to add a brief synopsis of the clinical history and autopsy of the case of a woman observed by Professor Charcot and myself at the Salpetrière, through a number of years.

1871. Sudden attack; loss of consciousness; right hemiplegia.

1873. Contracture of the paralyzed limbs; sensibility in the affected side much diminished; senses of taste and smell equally affected on the same side; vision lost on right side, very imperfect on the left; conjugate deviation on the right side.

1874. Rage for tearing herself; she scratches her face, arms, legs, and especially the thigh of the paralyzed side. Face a little deviated to the left.

Examination of the eyes revealed to me a total amaurosis and white atrophy of the disks; sensibility obtuse; contracture persists.

1876. Sensibility returned. Paralysis and contracture remain.

1877. Falling of the right lid nearly complete; ocular movements intact; pupils equally dilated; complete loss of vision.

1878, March 27th. Death.

Autopsy.—Multiple cortical *remolissements* not having their seats in the motor regions. *Central remolissement on the left side which had invaded the optic bed and the corpus geniculatum of the same side.*

Atrophy and degeneration of the corpus geniculatum externum of right side. Atrophy of the two optic tracts, of the chiasma and the optic nerves (the right a little more atrophied than the left).

Tubercula quadrigemina anteriora degenerated and of a yellowish tint.

The following parts are healthy: the tubercula quadrigemina posteriora; the corpus geniculatum dextrum, and the optic bed of the same side.

Secondary degeneration of the cerebral peduncle and anterior pyramid of the left side.

This case speaks strongly in favor of a crossing of those fibres of the optic nerves which do not cross at the chiasma; as well as for the termination of the optic fibres of each eye in the neighborhood of the corpora quadrigemina anteriora.

LECTURE XVI.

OPHTHALMOSCOPY.

Gentlemen:—Among the methods of examination with which ophthalmology has been enriched during the last twenty years, some of the more important of which we have examined in the preceding lectures, the ophthalmoscope holds the first place, and for a variety of reasons.

It is the ophthalmoscope which, by rendering the interior of the eye accessible to exact examination, has raised ophthalmology from the ranks of empiricism and placed it on the firm ground of science, where it has made a progress as rapid as it has been brilliant.

It is the ophthalmoscope which has brought such efficient aid to ocular anatomy and physiology, particularly in the study of the structure and functions of the deeper portions of the eye, and of the properties of its dioptric apparatus.

In pathology the ophthalmoscope has also inaugurated a new era. All questions appertaining to amblyopia and amaurosis, hitherto so obscure, have become, probably, the best studied and most clearly understood of any in human pathology.

The diseases of the membranes at the fundus of the eye are diagnosed in their incipiency, and followed in their development in their most minute details. We see, for example, a choroiditis taking its origin in the peripheral portion of the vascular membrane of the eye, extending gradually toward the equator, approaching the posterior pole, and finally invading the part most essential to vision. We see it begin under the form of a simple hyperæmia, accompanied here and there by exudations and

hemorrhages, to afterward cause alterations in the pigmentary coat of the fundus, alterations which manifest themselves in some places as atrophy, in others as a massing of the pigment.

We see, at the same time, the inflammation of the choroid communicated to the retina; the pigment migrating into the nervous layer and forming deposits along the walls of the vessels.

We can see, also, the interference in the process of nutrition which results from it in other parts of the eye; the vitreous humor is filled with floating bodies, the posterior surface of the lens becomes opaque, and finally the whole lens loses its transparency, and intercepts the passage of light.

We follow, with the same facility, the evolution of all the other affections of the fundus of the eye.

In another branch of ocular pathology the application of the ophthalmoscope is equally satisfactory. With it we are enabled to determine the refractive condition of the eye with great certainty.

But it is not ophthalmology alone which has derived such immense advantage from the invention of this important instrument. It has thrown much new light upon general medicine. Physiology has recourse to the ophthalmoscope for the purpose of studying, during life, the phenomena of the circulation of the blood, and the condition of the nervous substance under the influence of various cerebral disturbances.

We frequently find written on the bottom of the eye the diagnosis of an organic or diathetic affection, even when all the other symptoms do not suffice to establish it. The ophthalmoscope has often revealed the beginning of a general disease before any of the ordinary symptoms characteristic of it had made their appearance.

I would call your attention, in support of this assertion, to tubercles of the choroid, retinitis albuminurica, optic neuritis, and "choked disk," symptoms pathognomonic of various troubles in the brain.

I have scarcely need to speak of simple anæmia, characterized by pallor of the optic nerve, or that form of anæmia called pernicious, which is revealed, under the ophthalmoscope, by multiple hemorrhages in the tissue of the retina. And I need hardly add syphilitic retinitis, and the phenomena of pulsation of the central vessels of the optic nerve in diseases of the heart. All these are ophthalmoscopic symptoms most important for the diagnosis of general diseases.

The importance of the ophthalmoscope is universally recognized, and it would be a great gain to medicine if all physicians were perfectly familiar with the use of the instrument. Indeed, it is so simple, and its employment so uncomplicated, that it would seem, at first sight, that nothing would be so easy as to see the bottom of the eye. It is, however, not so easy as it appears.

In order to profit as much as possible by the instrument it is necessary to understand the principles of its construction and to take an account of the conditions which govern its employment.

These two facts are too frequently lost sight of by the practitioner, and the object of these lectures on ophthalmoscopy is to set forth the principles on which the ophthalmoscope is made, and instruct you how to use it to the best purpose. We shall confine ourselves to questions strictly practical, without entering into special theoretical details. We shall refrain, also, from a description of the innumerable variety of forms which the ophthalmoscope has assumed since its invention, simply limiting ourselves to the most important modifications.

We will omit, also, a description of the various pathological conditions of the fundus of the eye, leaving this to works on the pathology and pathological anatomy of the membranes of the eye, to which it belongs.

THEORY OF THE OPHTHALMOSCOPE.

The ophthalmoscope is an instrument enabling us to see the interior of the eye; but a large majority of individuals, perhaps,

do not know why it is that we have need of an instrument to thus look at the fundus oculi. What, indeed, is it that prevents us from seeing, with the naked eye, the optic nerve, the choroid, the retinal veins, etc., since all the structures situated in front of them are transparent? Why is it that the pupil appears black, although the fundus of an eye looking toward a light is evidently illuminated?

These questions have occupied the attention of *savants* for centuries, and many theories have been formed for their solution, all more or less plausible. It was thought, for example, that the pigment of the choroid absorbed all the light penetrating the eye. This theory cannot hold good, because the pigment of the choroid is far from being absolutely black. It therefore reflects a good part of the light; but beside the pigment of the choroid and retina there are many other objects in the fundus of the eye which absorb only a very small portion of the light incident upon them, as the retinal vessels, papilla, etc.

Again, the opinion was promulgated that the light, in order to be perceived by the optic nerve, must be transformed in the retina into a kind of physical force, such that it could not return again as light from the bottom of the eye, etc.

It was only in 1851 that Helmholtz gave a solution to the problem, and showed why, in ordinary conditions, we cannot see the bottom of the eye when it is illuminated. He explained it as follows:—

The light coming from an illuminated portion of the fundus of the eye follows the same course in leaving the eye as it did in entering it, that is to say, it is directed toward the source of illumination.

The well known laws of conjugate foci are applicable here. As is well known, a luminous point and its image formed by an optical instrument are called conjugate foci. The law governing these foci is as follows: *the luminous rays coming from an object follow exactly the same path as those which come from its image formed*

by an optical system, and consequently *we can indifferently replace the image by the object, and the object by the image.*

Thus, suppose that we take (as in Fig. 30) a convex lens, for example, No. 20 D; if we place a candle at a certain distance in front of it, and a paper screen behind it, just at the point where the image *l* of the candle is formed, the points which make the object and the corresponding points of the image are conjugate foci. If we now place the candle in the place of the screen and the screen in the place of the candle, we will find that the image is formed just where the object was before; an experimental demonstration of the law of conjugate foci. This law is very important in the theory of ophthalmoscopy, and we shall have frequent occasion to refer to it.*

FIG. 30.

Thus, already, in regard to the illumination of the bottom of the eye, this law enables us to see at once why, under ordinary conditions, the fundus of the eye is not visible.

Let us put our lens in a tube. We find an apparatus of this kind already prepared for us in the ocular of a microscope when the upper lens is removed. Close the open end of the tube with a piece of white paper, and place a light some meters in front of

* I would recommend the reader to make for himself this simple experiment, which renders the theory of the ophthalmoscope and the formation of the ophthalmoscopic image very clear and intelligible. Care should be taken, however, to use a very small flame, and not an ordinary candle, which gives a flame much too large. Instead of the flame an opaque screen with a perforation, of any desired form, covered by a piece of ground glass, can be used. A light placed behind this will furnish an object which is much better than the candle, for making the experiment.

the lens. On directing the lens toward the light you will see an image of the flame formed on the paper, and the part of the paper on which the image appears will be strongly illuminated, as you can convince yourself by looking at the paper from behind. The opening in the tube that is closed by the lens and crossed by the incident and emergent light appears, however, absolutely black when viewed from the front. The light which comes from the illuminated portion of the screen cannot enter the eye of the observer, because the rays take, on quitting the lens, the same direction they had when they entered it, that is, they come together again in the flame, according to the law of conjugate foci.

The same thing occurs in the eye.

FIG. 31.

Let, for example (Fig. 31, I), L be a luminous point situated in the flame to which the eye is adapted; *l* will be the image which is formed on the retina. This point *l* of the retina is, therefore, strongly illuminated; but the light which comes from it does not fall in an eye which is looking into its pupil; it follows, according to the law of conjugate foci, the same path taken by the incident light, and comes to a focus in the point L of the flame.

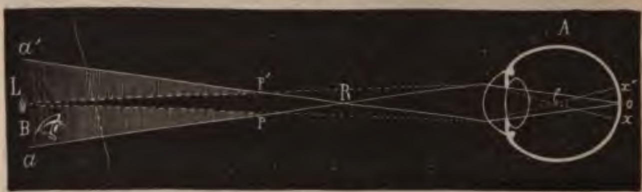
In order that the observer may see the retina illuminated he must place his eye in the cone of emergent rays L*pp*, which would not be possible without intercepting the light. The same

law would apply, of course, to all the luminous points composing the flame; the sum of their images illumine a part of the retina, and the rays emerging from this part are again united in the source of illumination.

But these conditions change *when the eye is not adapted to the flame* which illuminates it.

Suppose that, in our example, the retina is found *behind* the place where the image of the luminous object is formed (l, Fig. 32). Let, for example, the eye A be strongly *myopic*. Then, in place of a distinct image, the point L will form on the retina an image of diffusion $x'x$, and the luminous rays which come from this part of the retina, from the point o, for example, will not form their image any longer in L, but nearer the eye, at the point R, for

FIG. 32.



which the myopic eye is adapted. After their union in R the rays continue their course in a diverging manner, and thus form a luminous cone $P'P\,a'a$, in which the eye of the observer can be placed without interrupting the light. An eye placed in this cone will, therefore, receive the light coming from the fundus of the eye A, and will see it illuminated.

The same thing occurs when the retina of the observed eye is situated *in front* of the conjugate focus of the light.

Thus, suppose the eye in Fig. 31, II, to be strongly hypermetropic. The luminous rays coming from L, instead of coming to a focus on the retina, are united behind it in l, and form on the retina an image of diffusion xx'. On the other hand, the luminous rays coming from the point o of this illuminated portion of the retina are no longer directed toward the source of illumination,

but leave the eye in a divergent manner, as pa and $p'a'$. By placing his eye in this luminous cone, at B, for example, an observer can receive the light which comes from the bottom of the eye without intercepting the incident light, and without being much inconvenienced by it, especially if care is taken to shut off the glare of the lamp by a screen.

If we advance or withdraw the paper which closes the open end of the ocular of the microscope which we have taken to represent an artificial eye, we will see that while the image of the flame becomes diffuse we can distinguish the white of the paper through the lens, and by advancing or withdrawing it sufficiently we can even see the figures traced upon it.

The same phenomenon is sometimes manifest in the eye. It has been known for a long time that the eyes of certain animals shine when they are directed toward a luminous object. There are also certain affections of the eyes, especially intra-ocular tumors, which enable us to see into the interior of the eye without the intervention of the ophthalmoscope. One of these affections, glioma of the retina, has received, on account of this phenomenon and its analogy to the appearance of the eyes of certain animals, the name of *amaurotic cat's-eye.*

Mery and La Hire observed that it was possible to make the eyes of animals luminous by immersing them in water. They also showed that a reflex can be obtained from the interior of any eye by removing the lens or cornea, or both.

The explanation of these phenomena is not at all difficult after the experiments which we have just made. All eyes which shine spontaneously are in the condition which we have just been considering, that is to say, they are not adapted for the source of illumination.

Indeed, the animals whose eyes shine, such as cats, dogs, rabbits, cattle, etc., are all hypermetropic, and considerably so. All the rabbits whose refraction I have determined have possessed a H. of about 3 D.

Eyes affected with intra-ocular tumors, detachment of the retina, etc., are also hypermetropic, that is, the retina is situated in front of the focus of the incident rays. Thus, as is shown in Fig. 31, II, the rays which come from the illuminated part of the retina do not follow the path of the incident rays, but occupy a much larger space.

This is why we obtain a yellow reflex from the eyes of cats, and why we see directly, and without the aid of an ophthalmoscope, the retina which is detached, or affected with a gliomatous tumor, or is pushed forward by a tumor of the choroid. We can produce the same effect by making pressure with the finger on the fundus of an enucleated eye which is turned toward the light. The interior of this eye, which was dark before the pressure was made, now becomes luminous, from the advancement of the fundus.

And why do eyes deprived of their corneæ and crystalline lenses, and eyes that are immersed in water, shine? The answer is simple enough; while those eyes affected with glioma are hypermetropic by shortening of their antero-posterior axes, those deprived of their corneæ or lenses, or immersed in water, are hypermetropic on account of the diminution of their refracting power.

An eye which would have seen distinctly a light placed at no matter what distance, will no longer see it distinctly after an operation for cataract, because, the lens being taken out, its dioptric system is no longer able to unite the rays coming from the flame upon the retina. This eye, instead of having a clear image, has, therefore, an image of diffusion, as seen in Fig. 31, II, and the parts diffusely illuminated send out, in their turn, rays which, far from uniting in the source of illumination, are directed to all sides in a diverging manner.

For the same reason eyes which have been deprived of their corneæ are luminous. They are rendered hypermetropic by a weakening of their dioptric systems.

The same effect is produced in eyes immersed in water. Water

having nearly the same index of refraction as the aqueous humor of the eye, the cornea loses its power of refraction, and it is now the plane surface of the water which replaces the convex surface of the cornea and separates the refracting surfaces of the eye from the air. There is thus brought about a very considerable diminution of the refracting power of the eye, which is expressed by a hypermetropia of a very high degree.

These are the conditions in which we are able to see the fundus of the eye illuminated.

Exceptional conditions are met with, it is true, but they are conditions not ordinarily realizable in practice. Moreover, even although we receive a certain portion of the light which comes from the bottom of the observed eye, and although a certain number of these rays enter the eye of the observer, it is only a small portion of the emergent light which is thus available, and if the ametropia is not very great the greater part of the light still pursues its way toward the source of illumination; in certain cases the whole of it is united there. The illumination under which the fundus of the eye is seen, under these circumstances, is, therefore, of necessity, very feeble. It is, in the majority of cases, insufficient for making out the finer details.

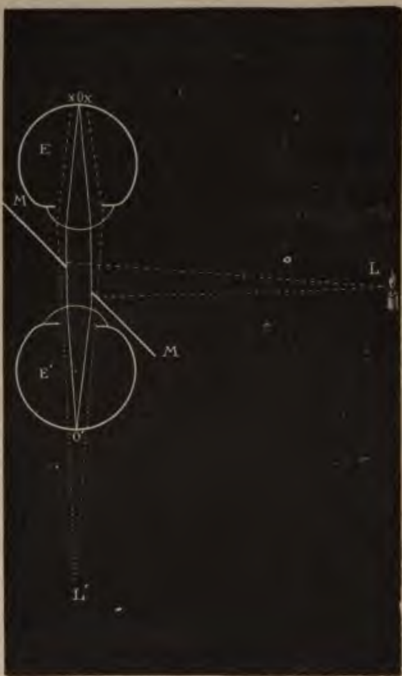
It is remarkable that all these known facts did not suffice to furnis hour ancestors with a means of examining, during life, the optic nerve, the retina and the choroid, as we are now able to do with such facility and success. In order to see the interior of the eye in a satisfactory manner it does not suffice to look obliquely into it and to receive some of the scattered rays at the periphery of the luminous cone which comes from it, but it is necessary that we be able to place the eye in the axis itself of the rays emerging from the eye under examination.

Helmholtz solved this problem in that simple manner which characterizes all great discoveries. In place of putting the light in front of the eye to be examined, he placed it at the side, and reflected it into the eye by means of a semi-transparent mirror, or

a mirror with a central perforation. Let E (Fig. 33) be the eye under examination, E′ the examining eye, L a source of illumination, and MM a mirror.

This mirror, held obliquely before the examining eye, reflects the light from L into it, as if it came from L′, and as far as regards the eye E, it is the same as if the flame was situated in L′. The eye of the examiner is found, therefore, in the direction of the incident rays, and the light which comes from the illuminated portion *xx* of the eye E will not all be reflected toward L by the mirror, but a portion will pass through the mirror if it is semi-transparent or has a perforation. This light falling on the eye of the observer will enable him to see the fundus of the eye under examination.

FIG. 33.



The essential part of the ophthalmoscope is, therefore, the *mirror* reflecting the light. The mirror of Helmholtz's ophthalmoscope is composed of a number of thin plates of plane glass, superposed one on the other. This mirror reflects a portion of the light which falls on it, while the other portion passes through it.

All manner of mirrors imaginable, plane, concave, convex, prismatic, single, or combined with convex lenses which concentrate the light on the mirror, have been used since the invention of this first one. Some have been made of metal and perforated in the centre, others are of silvered glass, with a portion of the silvering removed at the centre, or with a perforation.

In practice it has been found that the *concave mirror with a central perforation* is the most convenient. It is not a matter of much importance whether the mirror be of metal or glass. The advantage of the concave mirror is that it concentrates the light, thus giving the most powerful illumination.

However, in many cases a feeble illumination is preferable, especially so when the eye under examination cannot bear the light, in consequence of inflammation of its deeper structures, or where the pupil is strongly contracted by bright light. In such cases the *plane* mirror can be employed with great advantage.

Experience has shown that the mirror best suited for practice should have a diameter of 28 millimeters and a focal distance of 18 centimeters. The plane mirror should be of the same size. The central perforation ought to be at least 3 mm. in diameter.

LECTURE XVII.

EXAMINATION OF THE ERECT IMAGE.

GENTLEMEN:—As we now know the means for illuminating the bottom of the eye, we have no need, in what follows, to occupy ourselves with the source of the illumination. We suppose it already illuminated, and now ask, What is necessary in order that we be able to make out the details of the fundus? It does not suffice that the eye be simply illuminated, and that we receive the light from the part of the retina thus illuminated; we must see distinctly all its parts in detail. Now, in order to see an object distinctly a clearly defined image of that object must be formed on our retina. We must, therefore, endeavor to find the conditions necessary for the *formation of a distinct image of the bottom of the eye under examination on the fundus of the eye of the examiner.*

This is not altogether a simple matter, since we do not look at the fundus of the eye directly, as we look, for example, at the membrana tympani by means of the otoscope, but through a refracting system—the dioptric apparatus of the eye under examination. This dioptric system gives to the luminous rays which come from the bottom of the eye a certain direction, which differs essentially from that which they would have had if they had simply passed through the air.

The basis of the study of these questions is again the law of conjugate foci, according to which, in any dioptric system, we can replace indifferently the image by the object and the object by the image; or, expressed differently, in every dioptric system

the rays of light which are directed toward a point follow the same course as those which come from that point.

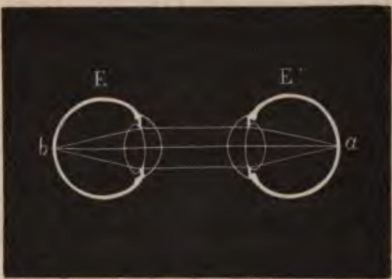
The convex lens, the small flame and the screen which we have used in the foregoing illustration of the law of conjugate foci will assist us in understanding easily the manner in which the ophthalmoscopic image is produced.

Let us suppose the lens to represent the dioptric system of the eye, and the flame an object on its retina. In this case we can disregard the light which illuminates the eye so long as the object on the retina is itself luminous.

We will suppose both the eye under examination and that of the examiner to be emmetropic. We know that in a state of repose the emmetropic eye is adapted for parallel rays. In order to see the fundus of another eye it is, therefore, necessary that the rays coming from it be parallel. Now, it is from the eyes of emmetropes that the rays emanate parallel to each other, and that, too, in accordance with the law of conjugate foci.

The rays which are united on the retina of an emmetropic eye must be parallel before reaching the eye, and therefore the rays are parallel after they pass out of it. Thus, in looking at Fig. 34 a point *b* on the retina of the examined eye E sends out rays which are parallel after their exit from it, and again are united in the image *a* at the fundus of the eye of the emmetropic examiner E′.

FIG. 34.



It is only necessary, then, for an emmetrope to throw the light by means of the ophthalmoscopic mirror into the eye of another emmetrope, in order to see objects at its fundus distinctly. The rays coming from the fundus of such an eye leave it parallel, and are united at the fundus of the examining eye which is adapted

for parallel rays. The examiner will thus see objects at the fundus of the examined eye in their natural positions, as are all objects which we look at through a lens at whose focus they are situated. It is for this reason that this procedure has been called *examination by the erect method.*

To represent an emmetropic eye in our experiment we must put the flame at the focus of the convex lens (20 D) at 5 centimeters behind it, since in the emmetropic eye the retina is found at the focus of the dioptric system. An emmetrope with a relaxed accommodation, in looking through the lens, no matter at what distance from it, sees an enlarged upright image of the flame.

But if the examined eye is *hypermetropic* the rays coming from

FIG. 35.

its retina are not parallel. If you look at Fig. 35 you will see that the dotted rays coming from the retina *a* are divergent on leaving the eye, and that they diverge as if they came from a point R situated behind the eye. The hypermetropic eye requires the rays to be *convergent* in order to unite them on its retina, and therefore the rays returning from it must be *divergent.*

Will the emmetropic examiner be able to see the fundus of this eye? In a state of perfect rest, no, since in that condition it has need of parallel rays to form a distinct image. He will, therefore, see the examined eye illuminated, but he will not be able to make out the details of the fundus. In order to see these details distinctly he must adapt his eye to divergent rays, or render the divergent rays parallel; in other words, either he must make his own eye myopic or the examined eye emmetropic. We have in the accommodation a very simple means of adapting our eye to

divergent rays. The emmetropic eye has, therefore, only to make an effort of the accommodation sufficiently strong to see distinctly an object placed at R, in order that the divergent rays coming from the hypermetropic eye be united on his retina in a clear and distinct image; he will then see the details of the fundus of the examined eye distinctly.

But if the examining emmetropic eye E (Fig. 35) is not able to adapt itself to the point R, either because the accommodation is too weak, or because the rays coming from the examined eye are too strongly divergent (R being too close to the eye—the hypermetropia being too great), or if it is desired, as is frequently the case, to see it without putting the accommodation in play, then the divergent rays must be rendered parallel; and this can be accomplished by means of a convex lens placed between the eye of the examiner and that of the examinee. You will readily see that the focus of this lens should coincide with the *punctum remotum* R of the eye under examination. In Fig. 35, L is the correcting lens of the hypermetropic eye H. It makes parallel rays converge toward R and, of course, renders parallel the rays coming divergent from R, or, what amounts to the same thing, those coming from *a* of the hypermetropic eye, since they leave the eye with a divergence as if they had come from R.

The emmetropic examiner can, therefore, see the details of a hypermetropic eye distinctly, either by illuminating it and bringing his accommodation into play, or by leaving his accommodation completely relaxed and putting a lens before the hypermetropic eye which corrects its anomaly of refraction. It is proper to remark here that, as far as regards the distinctness of the image, it is a matter of little consequence where the correcting lens is placed. We can, if the patient wears glasses, allow the glasses to remain on his nose, and look through the correcting lens with the ophthalmoscopic mirror, or we can put the lens behind the perforation in the mirror.

Let us return now to our artificial eye formed of a lens and

a flame. Since, in hypermetropia, the retina is found in front of the focus, we will only have to bring the flame nearer the lens than five centimeters to have a dioptric system similar to the hypermetropic eye. If we look through the lens we will see the flame upright and enlarged. It will require, however, a certain effort of the accommodation; an effort which will have to be the greater the closer the flame is to the lens (the stronger the hypermetropia); and also greater the nearer the observer brings himself to the lens and consequently to the *punctum remotum* of the hypermetropic eye, or the negative conjugate focus of the lens.

Suppose, finally, that the examined eye is *myopic*. You will

FIG. 36.

remember that the myope, in order to see clearly, that is, in order to unite the rays of light upon his retina, must have them come to his eye in a *diverging* manner. Thus, in Figure 36, the rays which come from the point R are united on the retina in the point *a*; therefore the rays which come from the point *a* of the retina are united in R. Consequently they are convergent on leaving the eye.

Can the emmetropic examining eye unite converging rays on its retina? Never. In a state of repose it unites parallel rays, and the power of accommodation enables it to unite diverging rays, but it does not possess any means of adapting itself to converging rays. The emmetrope will not, therefore, be able to see an upright image of the fundus of a myopic eye unless the converging rays coming from it are rendered parallel. In order to make converging rays parallel, we use a concave lens whose focus coincides with the point toward which the convergent rays are directed. This point

is the *punctum remotum*, R, of the myopic eye, and the lens is the correcting glass of the myopia. On looking at Fig. 36 you will see that the concave lens L gives to parallel rays a divergence as though they came from R; these rays can then be united on the retina at a. Therefore, according to the law of conjugate foci, the rays which come from a, and which, without a lens, would be united in R, become parallel in passing through the concave lens. The examiner can unite these parallel rays on his retina, and thus obtain a clear and distinct image of the fundus of the myopic eye. The principle is the same whether the glass is placed in front of the eye of the examiner or the examinee, but its lens must, in every instance, coincide with the *punctum remotum* of the eye under examination.

In order to represent myopia by means of our convex lens, we must remove the flame beyond the focus of the lens, that is, further distant than five centimeters, then by bringing the eye near the lens the examiner will no longer see the upright image of the flame distinctly. This will be a diffused image, and it will be the more diffused the further the flame is removed from the lens, that is, the higher the degree of the artificial myopia. But he will see it distinctly again if he places before his eye a sufficiently strong concave lens.

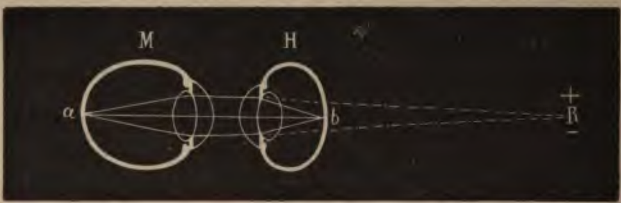
We have now shown how it is possible for an emmetrope to have a distinct *upright image* of the fundus of an emmetropic or ametropic eye. In order that an *ametropic examiner* have this image distinct it is simply necessary to correct his ametropia. By this means he becomes emmetropic, and the principles which we have just laid down become applicable to his eye.

There are certain conditions, however, in which ametropes are able to examine the eyes of other ametropes by the erect method without the intervention of the accommodation or correcting lenses. We have just seen that the light coming from the bottom of a hypermetropic eye leaves it in a divergent manner. It is evident that an eye which is able to unite divergent rays on the

retina can see the bottom of a hypermetropic eye without any other means than the ophthalmoscopic mirror. Such eyes are myopic, since they are adapted for diverging rays, and a myopic eye can see distinctly the details of the fundus of a hypermetropic eye when the rays coming from it have the necessary divergence.

Now, in leaving the hypermetropic eye H, Fig. 37, the rays appear to come from the *punctum remotum*, R, of that eye; on the other hand, in order to be united on the retina of a myope, the rays should come from its *punctum remotum*. It is requisite, then, that the *punctum remotum* of the myopic eye, and of the hypermetropic eye coincide, if they are to see each other's retinæ, reciprocally. This, however, is possible.

FIG. 37.



Let us take, as an example, a hypermetrope of 5 D. His *punctum remotum* is situated twenty centimeters behind his eye. If this eye is examined by a myope who brings his eye up to 2 centimeters in front of it, it will then be 22 cm. from the *punctum remotum* of the hypermetropic eye, and if its own *punctum remotum* is 22 centimeters in front of it, he can, of course, see clearly the details of the fundus of the hypermetropic eye, since their *puncta remota* coincide. Now, as the *punctum remotum* is situated in front of the eye it is myopic, and if it is at 22 centimeters, the myopia is $= \frac{100}{22} = 4.5$ dioptries. But if the myopia of the observer is only 4 D, that is, if its *punctum remotum* is found at $\frac{100}{4} = 25$ centimeters in front of it, he will not see the fundus of the eye under examination at 2 centimeters in front of it, but must remove his eye to 5 centimeters from that

of the hypermetropic eye, if he would see the fundus distinctly without an effort of the accommodation.

What is the refraction of the eye of an observer who sees, without the aid of his accommodation, or a correcting glass, the fundus of a myopic eye?

The rays coming from a myopic eye converge toward its *punctum remotum.* The examiner cannot be emmetropic, because the emmetrope requires parallel rays; much less can he be myopic, since the myope demands divergent rays; he must be hypermetropic, because it is the hypermetrope alone who requires converging rays. But we know that the rays coming from infinity are parallel, that those coming from a finite distance are divergent, and that converging rays are found naturally nowhere except coming from the interior of a myopic eye. It is, therefore, with reason that Jäger says that the fundus of a myopic eye is the only object in heaven or on earth which a hypermetrope is able to see without the correction of his ametropia.

Let us now return to the study of the conditions which we found, in the preceding paragraphs, as necessary for the formation of a clear and distinct image. The hypermetrope, deprived of his accommodation, cannot unite indifferently all convergent rays, but only those which are directed toward his *punctum remotum.* Now, since the rays coming from the eye of a myope are directed toward its *punctuw remotum,* it is absolutely necessary that the *punctum remotum* of the myope coincide with that of the hypermetrope, in order that the hypermetrope make out clearly the details of the fundus of the myopic eye in the upright image, without the intervention of his accommodation or a correcting glass.

If the eye has a myopia of 4.5 D its *punctum remotum* is situated at 22 centimeters in front of it, and that of the hypermetrope should be 20 *behind* it when his eye is 2 centimeters before the eye under examination.

There is no need to multiply examples. Understanding the

fundamental principles as we have given them, it is easy to follow out all the combinations possible, and to judge whether an ametrope of a given degree can see the fundus of another ametropic eye or not, and at what distance it must be placed. Moreover, when we have found the conditions necessary to enable any eye *A* to see the fundus of another eye *B*, the law of conjugate foci tells us that under the same conditions B can see the fundus of A if it turns the ophthalmoscopic mirror and illuminates it. If A sees the fundus of the eye B it is because the image of B's fundus is formed on his own retina. We have only to replace the image by the object, and the object by the image, according to the law of conjugate foci, and we readily see that, inversely, an object on the fundus of the eye A should form its image on the retina of the eye B, that is to say, that B should see the upright image of A.

LECTURE XVIII.

THE INVERTED IMAGE.

GENTLEMEN:—We open in this lecture a new question in the study of ophthalmoscopy. We have repeated, time and again, that the rays coming from the fundus of a myopic eye are convergent, and are united in its *punctum remotum*. If this is true, an image of the fundus of this eye must be formed at the distance of its *punctum remotum*, in accordance with the law of conjugate foci, which allows us to replace the image by the object and the object by the image. Since an object is seen

FIG. 38.

distinctly by a myope when at its *punctum remotum*, that is to say, since a distinct image of the object is formed on the retina, it follows that an object on the retina forms a clear and distinct image in front of the eye at the distance of its *punctum remotum*. We can easily convince ourselves of the truth of this. We have only to illuminate a myopic eye of 10 D, for example, from a sufficient distance, in order to see a real image of its retina formed at 10 centimeters in front of it.

An object B A (Fig. 38) which is situated at the *punctum*

remotum of the eye M forms on the retina of this eye an image *a b*, and, reciprocally, an object *a b* on the retina forms an image A B in the air in front of the eye. The image and the object, as you see, are inverted in relation to each other.

We can produce the same effect in our artificial eye composed of the flame and convex lens. Let us simulate the condition of myopia by removing the flame which represents the retina beyond the focal distance of the lens. By removing ourselves sufficiently far away from the lens we will see again the image of the flame, but it is not the same image which we saw before, when the myopia was corrected; the proof of this lies in the fact that we can only see it when we place ourselves at a certain distance from the eye, and that in order to see it distinctly we must bring our accommodation into play, because the image is situated *in the air between our eye and the examined eye.* Thus, retaining our example of a myopia of 10 D, if we place ourselves at 40 centimeters before such an eye the image of the fundus of the eye will be made at 10 centimeters in front of it, and 30 centimeters from our eye, and in order to see it distinctly we must, by our accommodation, adapt our eye to the distance of 30 centimeters.

We have only to place a screen between our own eye and the convex lens which represents our artificial eye, in order to be convinced that at a certain distance from the lens the image of the flame is produced on the screen.

The images which we have obtained previously, of the emmetrope, and the hypermetrope and myope, after correction, could not be received on a screen.

Let us again use the lens and flame. We place the flame in the focus of the lens, or, in other words, we correct the myopia which we produced by removing the flame beyond the focus of the lens. We will be able to see the flame through the lens, but, no matter where we place the screen, we will not be able to obtain any image of the flame upon it.

The ophthalmoscopic image of an emmetrope or a corrected

ametrope, as we see it in the simple illumination, is behind the eye, and *virtual*, while the image of a non-corrected myope is produced in front of the eye examined, and is *real*.

Another important difference is to be noticed, too, between this real image and the image we saw before, and that is that the real image is *inverted* while the other is *upright*. The same thing is seen when a myopic eye is examined at a distance, with an ophthalmoscopic mirror alone. If we cause the eye under examination to make slight movements the image of the fundus of the eye does not follow these movements, but is displaced in an opposite direction. If we cause the patient to look upward the image moves downward; if he looks to the left the image moves toward the right; and *vice versa*. Moreover, in observing the disk and remembering that the large vessels which come out from it are directed outward, you will see that in the image furnished by the myopic eye these vessels run in an opposite direction, inward, and if you have noticed the upright image in detail, and found a point of pigment, for example, above the disk, you will find it in the myopic image below. All these things go to show that the image is *inverted*. This, however, should not be astonishing. You have not forgotten that all images are formed on the retina inverted; therefore, if we replace the image by the object (always following the law of conjugate foci), an object on the retina ought, in its turn, to form an inverted image at the place where the object was. All myopic eyes, therefore, form, at the distance of their *puncta remota*, *real* and *inverted* images of their retinæ.

It may be asked, possibly, why it is that the emmetropic and hypermetropic eye do not form images at their *puncta remota?* In reply I would say that in order that an image be real it must be formed by the convergence of luminous rays.

Now, the rays emanating from emmetropic eyes, being parallel, cannot come to a focus and form an image in the air, and the

rays coming from a hypermetropic eye are much less able to do so, since they are divergent.

In speaking of the *punctum remotum* of a hypermetropic eye it must be understood always that it is *negative*, that is to say, it does not exist in reality, but only corresponds to the union of the rays coming from a hypermetropic eye and supposed to be prolonged backward, that is, to the point from which they appear to emanate.

Neither an emmetropic nor a hypermetropic eye, therefore, can produce an aerial image, because the rays which come from them do not converge, as do those coming from the myopic eye. But we are able to make both parallel and diverging rays converge by means of a convex lens; in other words, we can render an emmetropic or hypermetropic eye myopic by placing a convex lens in front of it.

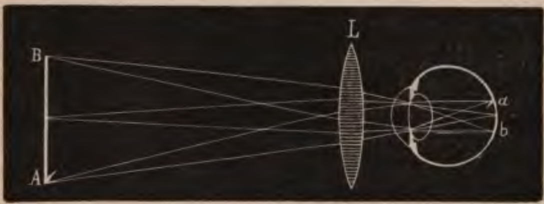
Place, for example, before an emmetropic eye a convex lens of 10 D. What will be its influence on the emerging rays? It will unite the parallel rays which come from the emmetropic eye at its focus situated 10 centimeters in front of it, or, what amounts to the same thing, it will give an emmetropic eye a myopia with its *punctum remotum* 10 centimeters in front of the lens. Our emmetrope, deprived of his accommodation, will read, with this glass of 10 D, the smallest print 10 centimeters in front of it; his eye will be adapted to this short distance in the same way as a myope's is to the distance of his *punctum remotum*. Inversely the objects on his retina will make their inverted and real images at the same distance in front of the lens. If we illuminate the interior of an emmetropic eye by means of an ophthalmoscopic mirror we will see an upright image of the fundus at any distance, without any effort of the accommodation. If we place before the same eye a convex lens, and remove our eye to some distance from it, we will see, by an effort of the accommodation, another image inverted and situated in front of the eye under examination.

Thus in Fig. 39 the object *a b*, at the fundus of the emmetropic

eye, forms, by means of the lens L, an inverted image, as, inversely, an object A B will form its image in *a b* on the retina.

The same thing occurs in a hypermetropic eye. If the convex lens is sufficiently strong, it will render the divergent rays of the hypermetropic eye convergent, so that they will be united and form an inverted image in front of the eye, not at its focus, but beyond it, and nearer the observer, since the rays coming from the eye observed are not parallel, but divergent.

FIG. 39.



In order to obtain an inverted image of the fundus of an emmetropic or hypermetropic eye, we must, therefore, place a convex lens in front of it, while for the myopic eye this image is produced spontaneously, at its *punctum remotum*, without the intervention of any lens. We can thus easily examine the eyes affected with a considerable degree of myopia (from 10 to 20 dioptries) with a simple mirror; but for myopia of less degrees, this method is not practicable. If we have a myopia of 2 D, for example, there is no doubt but that there will be an inverted image of its fundus formed at 50 centimeters in front of it, but how can we illuminate an eye with an ordinary ophthalmoscopic mirror at a distance of more than 80 centimeters? For, in order to see the image we must be at 30 centimeters distance from it. This is not practicable, because the illumination becomes too weak, and because the enlargement of the inverted image becomes so great that the image of a single branch of one of the retinal vessels fills the whole of the pupillary field, and we cannot make out the details and their relations with any satisfaction. What

should we do in such a case? We should use the same means which we have just used for the emmetrope and hypermetrope. Since the myopia is too feeble, we increase it by placing a positive lens in front of the eye. The inverted image is formed too far from the eye, so we unite the rays closer to it, by increasing their convergence by means of a convex lens. The inverted image in this case is found nearer to the lens than in emmetropia, that is, within its focus.

LECTURE XIX.

THE SIZE OF THE OPHTHALMOSCOPIC IMAGES.

GENTLEMEN:—Recurring again to our primitive artificial eye, we find that it discloses to us yet other valuable facts. Make this eye emmetropic or hypermetropic, by bringing the flame up to the focal point of the lens, or within it. We see again the image upright. By interposing between our eye and the lens which represents the eye to be examined a convex lens, No. 10, for example, we see the image change immediately, from the upright to the inverted. By comparing this inverted image with the upright image, the striking fact is revealed that the upright image is much the larger.

The upright image of the living eye is often so large, indeed, that we cannot see the whole of the papilla in the field of the pupil; often a single trunk of the retinal vessels is sufficiently large to fill it, while the inverted image can be made so small as to enable us to see at once not only the whole of the papilla but a large portion of the retina surrounding it.

Moreover, if, in making the inverted image, we employ different convex lenses, we shall find that the inverted image obtained by a weak lens is larger than that given by a stronger one, and furthermore, that it is formed at a greater distance from the lens than the latter.

We shall find, too, that the inverted image formed by the emmetropic eye with the same lens, has always the same size, whatever may be its distance from the eye.

On the other hand, the size of the inverted image of the hyper-

metropic eye diminishes in proportion as the lens is removed from the eye.

By removing the lens from the myopic eye, on the contrary, the size of the inverted image increases.

If we should compare the inverted images obtained by the same lenses, at the same distance from an emmetropic, hypermetropic and myopic eye, we should, of course, find that the image of the hypermetropic eye was larger, while that of the myopic eye was smaller than that of the emmetropic eye. From which fact the three following very important laws have been established.

1. *The upright image of an eye is larger than its inverted image obtained by the aid of a strong convex lens.*

2. *The size of the inverted image is proportional to the focal distance of the convex lens used* (inversely proportional to its refracting power).

3. *The inverted image of a hypermetropic eye is, other things being equal, greater than that of the emmetropic eye, and that of the emmetropic eye is greater than that of the myopic eye.*

These are very important facts; but they give us only *relative* ideas; they indicate the relations which exist between the size of the various ophthalmoscopic images, without giving us the least hint as to the *absolute* size of the images, or even the relations which they bear to the size of the object. The enlargement of the ophthalmoscopic image is a totally different question. You must not forget that the interior of an eye examined with the ophthalmoscope is not looked at under the same conditions as an object viewed in the air, as, for example, the membrana tympani, which we observe by means of an otoscope. We look at it through a dioptric system, namely, the refracting apparatus of the eye under examination, to which we sometimes add a lens, to correct the ametropia or to produce the inverted image.

It is hardly necessary to say that, under these circumstances, the objects at the fundus of the eye do not appear of their natural size. Indeed, in the examination by means of the upright image,

the fundus of the eye is situated at or near the focus of a magnifying lens, and all objects seen under such conditions are magnified. In the examination of the inverted image the fundus is found, as we have seen, beyond the focus of the magnifying lens, since the image it produces is inverted, and for convex lenses, which we generally use in ophthalmoscopy, this inverted image, though smaller than the upright image, is still larger than the object which produces it.

It is not an unimportant matter to determine the enlargement of the ophthalmoscopic image. What would you say of a histologist who would not take account of the enlargement of his preparations under the microscope, and what should we think of those ophthalmologists who do not endeavor to find out the real dimensions of those parts of the eye which they examine with the ophthalmoscope? I repeat, that this question has a great practical importance, and is not interesting simply from a scientific point of view, since it is not a matter of indifference to know the real size of a foreign body which the ophthalmoscope shows us in the fundus of the eye. Neoplasms at the fundus or in the interior of the eye are likely to remain to us an unsolved mystery, if we do not take account of their real size; but it is especially for the purpose of studying the *topography* of the fundus that it is important to reduce the ophthalmoscopic image to its real size.

It is of great importance to know what part of the eye we are examining; if such and such an affection of the fundus is found very near or very far from the macula; at how many millimeters from the papilla a foreign body is lodged, which we propose to extract. It will diminish considerably the chances of success of this operation, which, however, is sometimes successful, if we cannot put a just estimate upon the seat of the foreign body, such as can only be obtained by a knowledge of the real size of the ophthalmoscopic image.

This question, however, is not one very easy of solution, and it cannot be solved without the assistance of mathematics; and

since it is in accordance with our plan to adhere strictly to the practical side of our subject, we shall not go outside of it now to consider this matter, but simply refer those who desire to go into the subject fully to my monograph on the enlargement of the ophthalmoscopic image,* and to the chapter on the same subject in the *Compendium d'ophthalmologie,* by Wecker and Landolt. I have treated the subject in detail in those places, and I shall here limit myself to giving the results obtained.

The enlargement of the upright image depends on the distance to which the image is projected; in other words, on the distance at which the observer thinks he sees it. If this *distance of projection,* as I call it, is 30 centimeters, that is, if the observer projects the image to a point 30 centimeters in front of him, the enlargement of the upright image will be 20 times.

The *inverted image produced by a convex lens of* 20 *D* (+$\frac{1}{2}$ *O.S*) *placed at* 47 *millimeters in front of the cornea is, for the* EMMETROPE, 3.6 *times greater than the object; it is* LARGER *for the* HYPERMETROPE, SMALLER *for the* MYOPE; *and this difference increases with the increase of the ametropia.* It is, however, not very considerable; thus the inverted image of a hypermetrope of 7.9 D ($\frac{1}{5}$ O.S) is 4.1 times larger than the object; for a myope of 7.9 D the image is 3.1 times larger than the object.

The relation of the size of the inverted image of an ametrope, under the circumstances mentioned, to that of the upright image, is, therefore—

For *emmetropia* = 1 : 5.5.

For *hypermetropia* of 7.9 D = 1 : 4.7.

For *myopia* of 7.9 D = 1 : 7.1.

It follows from this that we should use the inverted image when we wish to take a general view of the background of the eye, while the upright image is to be employed when we wish to study it more in detail.

* *Le grosissement des images ophthalmoscopiques.* **Paris, 1874.**

LECTURE XX.

DETERMINATION OF THE REFRACTION BY MEANS OF THE OPHTHALMOSCOPE.

GENTLEMEN:—The course of luminous rays which enter the eye, as well as that of the rays coming from its interior, depends, as we have seen, on the condition of the refraction of the eye. In ophthalmoscopy we have to do with both the incident and emergent light: the incident light being that with which we illuminate the eye, the emergent light that which forms the ophthalmoscopic image. Now, the refraction of the eye influences not only the course of the emergent light which forms the ophthalmoscopic image, but also that which we throw into the eye, and that, too, in a variety of ways. Ophthalmoscopy should, therefore, furnish us, not with a *single* method only, but with *many* methods for determining the refraction of the eye examined. We can determine the refraction of the eye by means of the incident light; we can determine it again by means of the lens which it is necessary to use in order to see the upright image; by means of the enlargement of this image; by means of the distance at which the inverted image is formed; and finally, by the enlargement of the inverted image.

The sipmlest and most practical of all these methods consists in *finding the lens which the examiner needs in order to see the fundus of the eye under examination, distinctly.*

After what has gone before, this method requires but little further explanation. We have seen that the eye of the examiner being emmetropic, the lens which it is necessary to use in order to see the erect image of the fundus of another eye depends upon

the refraction of the eye to be examined, and that the number of the lens used to give a distinct image marks the degree of the ametropia.

You must not forget the one essential condition for determining the refraction: *the eye of the examiner, as well as that of the examinee, must have its accommodation completely relaxed.*

If the examination is made in a dark chamber, and the examinee is told to look as if at objects in the distance, the accommodation is nearly always completely relaxed. The proof of this is that the refraction, as determined by the ophthalmoscope, is nearly without exception less than that found by the usual means of test glasses, and nearly always corresponds with that found after the accommodation has been overcome by atropine.

It is indispensable that the observer habituate himself to relax his accommodation during ophthalmoscopic examinations. In order to do this emmetropes and hypermetropes must accustom themselves to look through convex lenses at objects situated at the focus of the lens, and to practice bringing their eyes to a condition of parallelism. This latter can be accomplished by placing before one eye a prism with its base inward. We have also found it of advantage to observe the inverted image through a tolerably strong convex lens (+ 3 D), in order to accustom ourselves to relax the accommodation in all examinations with the ophthalmoscope. Those who are not able to completely control their accommodation, should find the point to which they are able to relax it, and then consider themselves myopes whose *puncta remota* are situated at the distances for which they adapt their accommodation.

Finally, it is very important to know what point of the eye to choose as an object for determining the refraction. It is evident that in the majority of cases we will wish to take the refraction in the direction of the visual axis, that is, in the direction of the *macula lutea.* But the macula is not a good point to select. In the first place, there are no objects there with clearly marked outlines by which the examiner is able to judge whether his eye is

accurately adapted or not; in the second place, the light of the ophthalmoscope falling directly on the *macula* dazzles the observed eye to such an extent that the pupil contracts and thus interferes much with the examination; finally, it is in the direction of the optic axis that the reflections from the refracting surfaces—the cornea, and the surfaces of the lens—are most annoying.

An object which serves much better than this is the papilla, with its clearly marked outline, which is sometimes bordered by a line of pigment, and with its vessels, which are clearly pronounced against the bright background. Furthermore, it is insensible to light, and the reflection from the cornea is thrown to one side, because it is not found on the line of vision of the observer when he is looking at the disk. It is only necessary to know, therefore, if the refraction at the papilla is the same as that at the *macula*; that is, whether the papilla and the *macula* are on the same plane relative to the dioptric system of the eye. A difference of a fraction of a millimeter in the length of the eye suffices to produce considerable differences in its refraction. Ordinarily, however, we can say, without any great error, that the *macula* and the *external border* of the papilla are about on the same level; it is only in excavations and protrusions of the optic nerve, and especially in staphyloma posterior, that we have to determine the refraction at the *macula* itself.

It is of importance sometimes to determine the refraction, not only for the central part of the fundus of the eye, but also for the peripheral portions. I, among other observers, have satisfied myself that, where myopia is produced by an elongation of the eye (axial myopia), it is less at the periphery than at the center. It may change to emmetropia, or even hypermetropia, at the peripheral portion.

We will now suppose that the *observer is emmetropic and deprived of his accommodation.* When he sees the fundus of another eye distinctly, without the aid of any correcting glass, by simple illumination with the ophthalmoscopic mirror, that eye

must also be *emmetropic*: if the examiner sees the fundus of the examined eye, the image of the fundus must be formed clearly upon his own retina, and in order that this image be distinct it is necessary that the rays coming from the examined eye be parallel, and parallel rays can only come from an emmetropic eye.

If, on the contrary, the emmetropic eye sees the fundus of another eye by means of a *convex* lens, as well, or better than without a glass, then the examined eye is *hypermetropic*; for, in order to see clearly, the emmetropic eye must have the rays coming to it parallel, and if the rays are parallel after passing through a convex lens, they must have been divergent before reaching it, and that divergence must have been the same as if the rays came from the focus of that lens. Now, it is only a hypermetropic eye which can send out divergent rays. The examined eye must, therefore, be hypermetropic, and its *punctum remotum* must coincide with the focus of the correcting lens. The degree of the hypermetropia is therefore given by the number of the correcting lens. If an emmetropic observer sees the fundus of a hypermetropic eye distinctly with a No. 4 convex lens, it shows that this eye has need of an increase of 4 dioptries in its refracting power in order to become emmetropic, that is to say, in order that luminous rays coming from it shall be parallel. He has, therefore, been 4 dioptries weaker than the emmetrope, and consequently his hypermetropia is 4 D.

We can consider the matter in yet another way. The correcting lens has rendered the rays coming from the eye of a hypermetrope parallel; therefore they were divergent, and, as we have said, the point of divergence is found at the focus of the lens, which coincides with the *punctum remotum* of the hypermetropic eye. Now, the focal distance of a lens of 4 D is $\frac{100}{4} = 25$ centimeters. The *punctum remotum* of the eye under examination is found, therefore, 25 centimeters behind the lens. If the lens is held at 1.5 centimeters before the eye the *punctum remotum* is found at 23.5 centimeters behind the apex of the cornea.

Here, you see, arises the question of the distance which separates the eye and the correcting glass. It is apparent that it is a matter of no little importance where the glass is held. If it is brought as close as possible it will not be far from the anterior fôcal point of the eye, which is 13 millimeters from the cornea. It ought, therefore, to have the same power as the lens which we have found in determining the refraction and acuteness of vision subjectively by means of glasses, and as we took in this method the number of the glass as a direct expression of the degree of ametropia, so we shall make no reduction of the number when we determine the refraction by the ophthalmoscope when the correcting glass is found near the same place.

This reduction would only be necessary in the case where the correcting glass is further removed from the eye to be examined, and especially in the high degrees of ametropia, where a difference of some millimeters in the focal distance of the lens will make a considerable difference in its refracting power. In this case we have only to remember that the focus of the correcting lens and the *punctum remotum* of the eye under examination coincide. Therefore, in order to find the real degree of the hypermetropia we will have to subtract from the focal distance of the correcting lens the distance which separates it from the cornea, or, if we wish to know the number of the glasses which the patient should wear at 13 millimeters from the cornea, we subtract from the focal distance of the ophthalmoscopic correcting glass the distance which separates it from a point 13 millimeters in front of the cornea.

Thus, suppose that the ophthalmoscope is held at 25 millimeters from the cornea of the observed eye, and that No. + 8, whose focal distance is 125 millimeters, is required to see the fundus clearly by the erect method. The *punctum remotum* of this eye is then found at $125 - 25 = 100$ millimeters behind the cornea; the real hypermetropia is therefore 10 D, and a correcting lens placed at 13 millimeters in front of the cornea will have to have a focal distance of $100 + 13 = 113$ millimeters, which is 9 D.

When the emmetropic examiner has need of a concave lens in order to see the fundus of an eye, that eye is *myopic;* the luminous rays which have been rendered parallel by the concave lens must have been convergent before reaching the lens, and have come, therefore, from a myopic eye. These rays must have had such a convergence, too, as would bring them to a focus at the *punctum remotum* of that eye. The number of this concave lens gives, therefore, the degree of myopia of the examined eye, provided it is not held too far from it. If it is found that the fundus of an eye can only be seen distinctly with a No. 5 concave, that eye will have a myopia of 5 dioptries. Its *punctum remotum* should be at the focus of the lens, that is, at 20 centimeters in front of the lens, or at $20 + 1.5 = 21.5$ centimeters in front of the eye. The observer, by removing his eye to a distance, can see with the ophthalmoscopic mirror alone, without any auxiliary lens, the inverted image of the fundus formed at this place.

If the ophthalmoscope is held at a greater distance from the cornea, say at 25 millimeters, and it requires a No. 8 to see the fundus distinctly, we know that the *punctum remotum* of that eye is to be found at 125 millimeters in front of the lens, and therefore at $125 + 25 = 150$ millimeters in front of the cornea, and the true degree of the myopia is $\frac{100}{15} = 6.5$ D. The correcting glass, placed at 13 millimeters in front of the cornea, ought to have $150 - 13 = 137$ millimeters focal distance, and, therefore, 7 D refracting power.

When the examiner is not emmetropic, but ametropic, the correcting glass which is required to see the erect image distinctly is evidently not the expression of the state of the refraction of the eye examined, because it does not render the rays coming from this eye parallel, but renders them *convergent* or *divergent,* according as the observer is *hypermetropic* or *myopic.* We must then subtract the part which serves to correct the ametropia of the examiner from the number of the glass found. Thus, a *hypermetropic examiner* who sees distinctly with a convex lens

would not say that an eye had a hypermetropia equal to the number of the correcting lens, because a part of the refracting power of this lens serves to correct his own hypermetropia, and this part must be subtracted from the number of the correcting lens.

The same holds true for the *myopic examiner* who sees distinctly with a concave lens. A part of the refracting power of this lens serves to correct his own ametropia, and must, consequently, be subtracted from the number of the correcting lens.

But the determination of the refraction becomes as simple for the ametropic examiner as for the emmetropic when his ametropia is corrected. Many of our ametropic colleagues have adopted our suggestion to put in the central opening of the mirror the lens which corrects their ametropia. By doing this they are always in a state of emmetropia while making ophthalmoscopic examinations, and the lenses of the ophthalmoscope which are used to determine the refraction of the examined eye serve them as well as emmetropes. This was in the time of the old system of numbering glasses, when it was so inconvenient to subtract the fraction which represented their ametropia from that of the correcting lens. With the new system of numbering, however, this calculation is so simple that it would be superfluous to put a special correcting lens in the ophthalmoscope.

Suppose the *hypermetropia* of the *observer* is 2 D. His refraction is 2 dioptries feebler than that of the emmetrope. From the correcting glass of which he has need to see the fundus of an eye under examination, it is always necessary to subtract the two positive dioptries which serve to correct his own hypermetropia. Thus, when our hypermetrope sees, with a convex No. 5, the fundus of an eye under examination, this eye has not a hypermetropia of 5 D, because two of these 5 dioptries go to correct the hypermetropia of the examiner. The hypermetropia of this eye will, therefore, be only $5 - 2 = 3$ D.

If our hypermetrope sees with $+ 2$ D, the eye examined must

be emmetropic, since $2 - 2 = 0$, or, better expressed, because these two dioptries render his eye emmetropic by completely correcting his ametropia, and the emmetrope sees the fundus of another emmetropic eye distinctly, without the intervention of any glass.

If the hypermetrope sees without any correcting glass, then the examined eye has an excess of refraction equal to the lack of refraction in the examiner's eye. In the example we have taken the examined eye should have a myopia of 2 D, since $0 - 2 = -2$. This would be the number of the correcting glass which an emmetrope would require to see the erect image in that eye, and is also the correcting lens of a myopia of 2 D.

If the hypermetrope has need of a concave lens to see the fundus of an eye distinctly, then this eye has a higher degree of myopia than when the hypermetrope saw without a lens. Suppose our hypermetrope of 2 D is armed with a concave lens of 6 D. This lens increases his lack of refraction, and makes it = 8 dioptries; consequently the excess of refraction of the examined eye = 8 D, since, according to our calculation, $-6 + (-2) = -8$ D.

Let us take now a *myopic examiner*. His eye has an excess of refraction which can be compared to the addition of a convex lens to his dioptric apparatus. The correcting lens will, therefore, always be more feeble than is necessary to correct the eye under examination. The number of dioptries which represent the excess of refraction of the examining myope must, therefore, be added to the correcting lens, in order to obtain the refraction of the eye examined. If the examiner has M of 5 D, and he sees with a lens of + 1 D, the examined eye must be strongly hypermetropic, because the myopia of the examiner is already equal to a positive lens of 5 D, to which must be added yet another dioptry of the correcting lens. The hypermetropia of the examined eye must therefore be $5 + 1 = 6$ D.

If the myope of 5 dioptries sees without a glass, then the

examined eye has a hypermetropia of a degree equal to the myopia of the examiner, and the hypermetropia will be equal to 5 D.

When the myope has need of a concave lens feebler than his myopia, the examined eye is hypermetropic still, because a part of the myopia of the examining eye is neutralized by the concave lens, but there yet remains an excess of refraction. For example, if our myope of 5 dioptries had need of -3 dioptries to see the fundus of an eye by means of the erect image this eye should have a hypermetropia of $5 - 3 = 2$ dioptries.

If the myope sees distinctly with his correcting glasses, the examined eye is emmetropic, because the correcting lens renders the myopic eye emmetropic, $5 - 5 = 0$.

And if the concave lens, of which the myope has need in order to see the fundus of an eye in the upright image, is stronger than its myopia, then this eye is itself myopic, but not in a degree equal to the number of the correcting lens, because a portion of this lens serves to correct the myopia of the observer. In our example, an eye the fundus of which the myopic examiner sees in the upright image with -8, has a myopia of $5 - 8 = -3$ dioptries, because of the 8 dioptries 5 go to correct the myopia of the examiner.

LECTURE XXI.

DETERMINATION OF ASTIGMATISM BY MEANS OF THE OPHTHALMOSCOPE.

GENTLEMEN:—When two meridians of the eye have different refractions, each meridian gives rise to the same ophthalmoscopic appearances as an eye having that degree of refraction. The ophthalmoscopic image of such an eye would, therefore, differ in many particulars in the two unequal meridians. If, for example, the refraction is stronger in the vertical than in the horizontal meridian, the examiner will have need of a stronger correcting glass in order to see distinctly the lateral, the upper, and lower borders of the optic disk.

At the same time, the enlargement of the upright image will be more considerable in the vertical direction than in the horizontal; the disk will appear relatively elongated in its vertical diameter.

The opposite takes place in the inverted image, and, as the enlargement of an inverted image is less for myopia than for hypermetropia, and less for hypermetropia of low degrees than for the higher, so objects seen through a less refracting meridian furnish an inverted image larger than that formed by a more highly refracting meridian. Moreover, the size of the inverted image varies unequally in different diameters, according as the convex lens is approached to or removed from the eye. In removing or approaching, successively, the convex lens, the dimensions of the inverted image increase or diminish more rapidly in the more highly refracting meridian, and *vice versa*.

Finally, the distance which separates the inverted image from

the lens will be greater in the image formed by the meridian less refringent than in that by the more highly refracting.

Another characteristic of the astigmatic eye consists in the fact that external objects form on the retina images more or less distinct, according to the meridian by which they are formed, a fact of which we can convince ourselves in an examination by the direct method.

All these facts have their bearing in the determination of astigmatism by the ophthalmoscope.

The presence of *astigmatism* is revealed in the degree of sharpness of the different parts of the image in the direct examination; if we see clearly, for example, the upper and lower borders of the disk and the horizontal retinal vessels, while the lateral borders of the disk and the vertical vessels appear confused, then we can assert, with certainty, that astigmatism is present. When the appearances change, that is, when the vertical vessels become distinct, and the horizontal are confused when an effort of the accommodation is put forth, or on the employment of a stronger convex correcting lens or a weaker concave lens, then we know that the vertical meridian has a stronger curvature than the horizontal.

Indeed, in looking through an astigmatic eye at the retinal vessels which run in different directions, we are in the same conditions as when looking at a figure with radiating lines through a cylindrical lens. The lines perpendicular to the meridian for which the eye of the observer is adapted will appear distinct, the others indistinct, especially those which are parallel to the corrected meridian. When the adaptation is changed the appearances change too.

If the fundus of the eye had an object of a fixed form, if, for example, the disk was circular, then that form alone would suffice, in the erect image, to make the diagnosis of astigmatism. The disk would appear oval, with its long axis parallel to the meridian with the strongest curvature.

But, since the disk is frequently oval in a normal condition, and no portion of the eye has a constant form, the diagnosis of astigmatism is not always possible by means of the upright image alone. But it is quite otherwise when we compare the erect and inverted images together.

This is the most satisfactory method for determining the existence of astigmatism ophthalmoscopically.

If we find, for example, that the form of the disk in the erect image is elongated vertically, and becomes round, or even oval, with its long axis horizontal, in the inverted image, we then know that the dioptric apparatus is stronger in the vertical meridian than in the horizontal. A stronger refraction gives a greater enlargement in the erect image, a less enlargement in the inverted image. Other objects in the fundus, such as the retinal vessels, can also be taken as tests.

Javal has proposed, for the rapid diagnosis of astigmatism, to employ the inverted image by varying rapidly the distance of the lens from the eye, still leaving, however, the ophthalmoscopic field larger than the size of the disk. If astigmatism is present the disk will change its shape during this movement, and become elongated in opposite directions at the two extremities of the excursion of the lens.

In all these experiments it is indispensable to hold the convex lens exactly perpendicular to the axis of the observed eye, because the least inclination will give rise to an alteration in the form of the ophthalmoscopic image, and consequently to an apparent astigmatism.

A very elegant means of diagnosing astigmatism consists in observing on the fundus of the eye the image of a radiating figure which is interposed between the source of illumination and the mirror of the ophthalmoscope. Thus, in bringing four threads together, crossing at the centre in the form of a star, we can see on the fundus of the eye a shadow of that figure. If the eye is not astigmatic all the rays of the star will be equally distinct,

while in the case of astigmatism some will be more distinct than others.

I will not dwell on the ophthalmoscopic methods for determining the *degree* of astigmatism, since we will only rarely be called upon to make the determination in this manner. But I would recommend the employment of the ophthalmoscope in the *diagnosis* of astigmatism, since it is easy, and of great importance practically.

LECTURE XXII.

EXAMINATION OF THE FUNDUS IN DETAIL.

Gentlemen:—We know now the conditions which must be fulfilled in order that we see the fundus of the eye, and even the enlargement under which it is seen. We must next take into consideration what it is we see in the fundus when we look at it through an ophthalmoscope.

We will suppose the refracting media of the examined eye to be perfectly transparent, and the eye to be illuminated by means of the ophthalmoscope at a moderate distance. We now simply see the pupil to be of a bright and uniform red color, without being able to distinguish any distinct forms, except in the case of myopia of high degree, when we will see the inverted image in front of the eye. This red color is due to the blood which circulates in the vessels of the retina and choroid, especially the latter. By bringing our eye as near as possible to the eye under examination, and bringing our refraction in accord with its refraction, we will see the *papilla of the optic nerve and the retinal vessels*, which come out at its centre and are distributed on the retinal surface.

Toward the temporal side of the optic nerve we find the *macula lutea*. The retina in a normal condition being transparent, we are enabled to see the *pigmented epithelial layer* back of it, whose dark tone, mixed with the red of the vessels of the choroid, produces the fundamental color of the background of the eye. When the pigment is not abundant, as in blonde individuals, we can distinguish perfectly the large vessels of the vascular layer of the choroid.

In examining the fundus of the eye we direct our attention, in

the first place, to the *papilla of the optic nerve*, or *optic disk*, as it is most frequently called. This serves as a sort of point of departure for measurements and for fixing the topography of the fundus, and in a number of cases it is itself the seat of pathological alterations of a very characteristic nature.

In order to find the papilla of the optic nerve it is necessary to remember that in man the entrance of the optic nerve in the eye is found at about 15 degrees to the inner side and 3 degrees above the posterior pole of the globe of the eye. In order to bring the *papilla* in the visual line of the observer we cause the examined eye to be directed slightly upward and toward the nose.

By placing ourselves in front of the patient we can obtain this position of the eye with certainty by causing the patient to look at our right ear, if it is the right eye that is under examination, and at the left ear if it is his left eye.

Before our eye has been properly adapted to the eye under examination we see only a white and diffuse reflection in the red field. This white spot is the papilla, and it is to it that we should direct our attention, since it serves as a centre in making a topography of the fundus.

The papilla has the form of a disk (Fig. 40), sometimes circular, but more frequently oval, with its long axis vertical; exceptionally the long diameter is horizontal.

The contour of the disk is not, however, always absolutely regular. The color of the surface is a light, clear pink, and frequently it is more pronounced on the inner half. A white ring (*t*,) generally surrounds the disk. This is called the *scleral ring*, and it is bounded, in its turn, by a black or deep brown line, the *choroidal ring* (*p*).

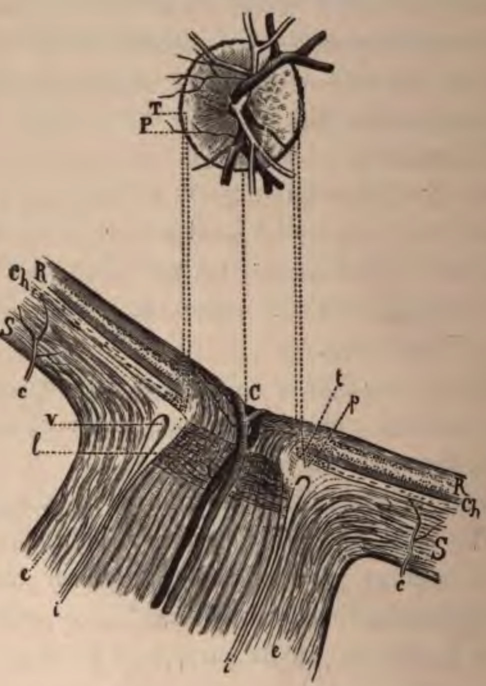
The centre of the disk is slightly excavated, and forms a kind of funnel, from which we see the trunks of the *retinal vessels*, the artery and vein, enter the eye. Each of the two vessels bifurcates near the level of the retina. These vessels are very clearly outlined on the clear background of the disk, and are directed

toward the outer side of the eye, distributing their branches over the whole extent of the retina.

But, before following the vessels up to their peripheral termination, we must pay attention to some other parts which give to the disk its characteristic appearance.

The optic nerve is enveloped by *two sheaths*, the *internal* (*i i*), more delicate, which adheres closely to it, and which is nothing more than a continuation of the pia mater; the *external* (*e e*), much thicker, corresponding to the dura mater. The two

FIG. 40.



sheaths are separated by a space called the *inter-vaginal space*, which is in direct communication with the sub-arachnoidal space. The internal sheath gives origin to the connective tissue which envelopes the nervous fibres of the optic nerve. Near the globe of the eye the outer sheath spreads out and separates itself more

and more from the inner sheath, and forms the external layer of the sclerotic (S S). The inner sheath accompanies the optic nerve still further and spreads out suddenly, to form the inner layer of the sclerotic. A third part of this tissue adheres to the fibres of the optic nerve up as far as the level of the choroid (*Ch*). The large transverse fibres bind this sheath of the optic nerve to the *tunica adventitia* of the retinal vessels, and thus forms the *lamina cribrosa* (*l*). Through the meshes of this pass the fibres of the optic nerve. Each of the fibres up to this point has had its sheath of myeline, which gives them their white and opaque appearance, but in passing through the *lamina cribrosa* they lose this sheath and retain nothing but their axis cylinders. They are then transparent, and are spread out on the retina (*R R*) to form its inner layer, that of the nerve fibres.

The nerve fibres which are directed toward the inner side of the retina are more numerous than those designed for the outer side, and they form a layer of greater thickness at the border of the papilla. Nevertheless, this hardly passes the level of the retina, and is thinner on the outer side than on the inner. It is, therefore, inappropriate to call the optic nerve entrance the *papilla*, which presupposes a prominence. The nerve entrance is protuberant only when there exists a neuritis with swelling of its ocular extremity.

The ophthalmoscopic examination shows us a section, as it were, of the optic nerve (Fig. 40), and the papilla is seen as a round disk, because the optic nerve is round; but it more frequently appears oval than circular, because the optic nerve and papilla are inserted sideways into the eye, and we see it more or less obliquely, and consequently it is shortened in its horizontal diameter. In other cases this oval form is due to a real irregularity of the optic nerve, or to an irregularity in the dioptric media, notably in astigmatism, which produces greater enlargement in one direction than in another.

The pink color of the disk is a mixture of the white of the con-

nective tissue of the *lamina cribrosa*, and the sheaths of the optic nerve fibres, the red of the blood which circulates in the capillaries, and the color of the axis-cylinders, which, although transparent, have, nevertheless, a slightly greenish or bluish tint. In ordinary conditions we find in the color of the disk a good deal of yellow and orange. This yellow is due to the artificial light with which we illuminate the fundus. In examination by day, with the white light of the sun, we can see but little yellow in the color of the disk. It is very interesting to make an examination by daylight, and see the difference of coloration of the fundus in the two lights.

As a proof that the white of the disk is due to the connective tissue and the red to the capillaries, I will cite the atrophy of the optic nerve, characterized microscopically by the absence of vessels, the disappearance of the axis cylinders and hypertrophy of the connective tissue, and ophthalmoscopically by a pure, brilliant white of the disk.

The inner part of the optic nerve, as we have said, is richer in nerve fibres than the outer part. Sometimes, with a high magnifying power, we can see on the outer part of the disk small, gray patches. They are especially noticeable at the beginning of atrophy of the optic nerve, and represent sections of the bundles of the nerve fibres around which the tissue of the *lamina cribrosa* forms lozenge-shaped figures, and which are visible for the reason that they are covered only by a few nervous fibres, either because the fibres are physiologically thinner or more transparent, or because they have disappeared through some morbid process.

There is another factor which has a considerable influence on the color of the disk, and that is the coloration of the fundus of the eye which surrounds it. If this last is very light, as in blondes, the papilla appears redder; if, on the contrary, the choroid is highly pigmented, and the fundus of a deeper tint, the disk will appear lighter. It is important to bear in mind the influence of this contrast, in order to avoid the mistake of supposing that in

the first instance we have a congestion of the disk, and in the second a beginning atrophy.

The *tendinous* or *scleral* ring which we see with the ophthalmoscope is the internal sheath of the optic nerve which is prolonged up to the choroid. It is larger in proportion as the perforation for the choroid is larger, or, in other words, as it is less covered by the pigment of the choroid. It is this pigment surrounding the tendinous ring that constitutes, when sufficiently thick, the *pigmentary ring* of the papilla. It may form a complete ring, or only a crescent, which is situated, in the large majority of cases, on the outer side of the disk. It may even be absent in eyes poor in pigment.

The vessels which we see emerge from the centre of the disk sometimes bifurcate in the *lamina cribrosa*. We then see two arterial and two venous trunks come from the disk. Most frequently this bifurcation takes place on the surface of the disk itself. In this latter case we see the common trunk of the vessels before its bifurcation.

One of the two principal branches of the artery and the vein is directed upward, the other downward, to run thence toward the periphery, describing an arc around the *macula*. In their course these trunks give off branches which are distributed to all parts of the retina.

So long as the vessels have the same direction as the optic nerve, they appear, like the surface of the disk, as if cut transversely, and on this account appear of a deeper color and sometimes irregularly dilated. After they are distributed on the plane of the retina, it is easy to distinguish the arteries from the veins. The arteries as well as their branches are thinner, lighter in color, and straighter than the veins, which are darker in color, larger, and more or less sinuous in their course.

We find, moreover, running along the centre of the arteries, a light, luminous line. This is due to a reflection of the light of the ophthalmoscopic mirror from the tense, cylindrical walls of

the arteries. This reflection follows the movements of the ophthalmoscope. It is less marked on the veins which are less tense, and consequently flatter.

The veins offer again, very frequently, another characteristic phenomenon, namely, *pulsation.* We see this pulsation in the larger trunks of the retinal veins (near the disk), never in the smaller branches. It consists in a rhythmical dilatation and collapse of the vessel, synchronous with the contraction of the heart. This is explained as follows :—

During the systole of the heart there is a diastole of the arteries which are filled with blood. At this moment the arterial pressure is evidently increased. This increase of pressure is communicated to the vitreous humor, which is not compressible, enclosed, as it is, in a very slightly elastic case, the sclerotic. It is, therefore, the veins, and especially the larger trunks, which offer the least resistance, and which feel most the increase of the intraocular tension. The further the blood has gone on its course the more its pressure diminishes. It is at the moment that they pass out from the eye that the tension of the retinal veins is the most feeble. The diastole of the arteries is, therefore, accompanied by a compression of the veins, which is propagated from the papilla toward the periphery of the retina.

This compression being made at the point of emergence of the veins, they are rendered in that part of their course almost filiform, and the flow of blood is accelerated toward the optic nerve.

But the afflux of blood by the capillaries not being arrested, the veins fill themselves more and more, and their tension increases up to such a point that the obstacle which the intraocular tension opposes to the exit of blood is overcome. This is accomplished much more quickly than the tension of the vitreous body diminishes at the approach of the systole of the arteries. The venous pulsation is not, therefore, a true pulsation, but rather a passive dilatation. This phenomenon is especially marked when we increase

artificially the intraocular pressure by pressing lightly on the eye with the tip of the finger.

The pulsation of the arteries is not visible in a normal condition. It only becomes so when the intraocular pressure is considerably increased, as is the case when we press on the eye with the finger.

We have a very marked venous pulsation, accompanied nearly always with arterial pulsation, in *glaucoma*, which, as you know, is characterized by an increase of the intraocular tension. A true venous pulse is produced by the regurgitation of the blood accompanying *insufficieny of the tricuspid valve.*

Insufficiency of the *aortic valves*, and the *mitral valve*, with or without hypertrophy of the left ventricle, is accompanied by a spontaneous pulsation of the retinal arteries. A very strong spontaneous pulsation of the arteries and veins is found in *Basedow's disease.*

The true pulsation, as we find it in the cases mentioned, differs from the pulsation caused by the increase of the intraocular tension (glaucoma), in this, that the rhythmic contractions of the arteries in the first case are transmitted throughout the whole trunk of the artery, while in glaucoma the alteration in the diameter of the vessels is seen hardly beyond the edge of the disk.

After the optic nerve, we examine the *retina*. It is so transparent that we are seldom able to see it in a normal condition; it is only under weak illumination that we can see it as a grayish or greenish veil in the thicker parts near the disk, or along the larger vessels. We can sometimes distinguish the very fine striæ which correspond to the nerve fibres.

The most important part of the retina is the *macula*. Anatomically it is represented by a slight depression in the retina, of a reddish-brown tint, with oval borders. It can be easily distinguished.

The macula corresponds to the posterior pole of the eye, and is the place of most distinct vision.

We have, therefore, theoretically, only to require the patient to

look into the centre of the ophthalmoscopic mirror, in order to be certain that we are looking directly at the macula. This, however, is attended with many inconveniences.

In the first place, the light is dazzling when it falls on any portion of the retina except the optic nerve (which is insensible to light), but particularly so when it falls on the region of the macula. The result is that the pupil is strongly contracted, and the ophthalmoscopic field consequently very much restricted. In the second place, the reflections from the cornea and crystalline lens are very annoying to the observer, because they are now just at the apices of the surfaces through which he looks.

We can more easily see the macula in the inverted image than in the upright. I cause the patient to look, not at the reflection in the lamp, but at the right side of my forehead in examination of the right eye, and the left half in examination of the left eye. I afterwards place the convex lens in such a way as to see, through its centre, the outer border of the papilla. Then, by moving the lens slightly to the outer side, the image of the macula follows the movement of the lens, and I can see it free from the corneal reflections, because these are displaced in an opposite direction from that in which the lens moves.

The macula can present many different appearances in a normal condition. Generally, it forms an oval with its long axis horizontal. This oval is bounded by a bright line, sometimes glistening, which, probably, is due to the reflection which the light undergoes at the border of the excavation of the macula. The bottom of this is dim, and of a much deeper red than that of the fundus generally. In some instances it is even brown or deep gray.

At the centre of the macula, which corresponds to the central depression, we find a point of intense redness, almost black. We find this especially in young individuals, and those whose eyes are strongly pigmented. Sometimes the bright line of which we have just spoken does not describe a complete oval, and the macula may be brighter, yet the dark point in the centre is hardly ever

absent. In other cases we see only traces of this image, and the macula is only to be distinguished by the absence of retinal vessels.

You must never neglect to examine the macula attentively. It is often the seat of a number of affections—hypertrophy or atrophy of the pigment, exudations, hemorrhages, etc.—which affect the vision considerably. These alterations will escape those who limit their opthalmoscopic examination to the disk.

After we have examined the disk and macula, we direct our attention to the *parts of the fundus surrounding them.* We have already said that these parts are, in general, a darkish-red color, which is more or less uniform.

This coloration is due, in part, to the layer of *pigmented epithelium of the retina*, and, in part, to the *vascular layer of the choroid.* Behind the transparent part of the retina is a thin layer, formed of quite regular hexagonal cells and filled with pigment. It is this pigmentary layer of the retina which gives to the bottom of the eye its more or less dark and granular appearance.

Behind the epithelial layer of the retina is the *choroid.* It is, as you know, the vascular membrane of the eye. Its stroma is pigmented, and we can easily distinguish a capillary layer nearer the retina, and a deeper layer which contains the large vessels.

It is mainly the vessels of the choroid which give the fundus its red color, modified by the blackish brown of the pigment cells. The richer these latter are in pigment the more they will hide the vascular layers and the darker the fundus will be, as we find it in those individuals and races which are strong in pigment.

If, on the contrary, the cells are poor in pigment, as is the case in blondes, then the red color predominates, and may even become bright red, and we are then able to see distinctly, here and there, the capillary vessels through the granulated brown of the epithelial pigmentary layer. Albinos, finally, in whom the pigment is totally absent, are very excellent subjects on whom to study the vascular system of the eye. We can distinguish perfectly in these the arteries and veins of the retina and the

capillaries and large veins of the choroid. We should mention, in passing, that it is on account of the enlargement produced by the dioptric media of the eye that we are able to distinguish the capillary vessels. They are seldom visible to the naked eye.

We examine the fundus of the eye, going from its centre in all directions up to the extremest limits at which we are able to illuminate it. We can do this either by making the patient look in various directions, or by changing our own position, or, better still, by a combination of the two methods.

As many serious affections begin at the periphery of the fundus, it is very important to explore the eye throughout its whole extent. It thus becomes possible to diagnose diseases in their incipiency, and even to anticipate them before other symptoms are manifest. Thus, *retinitis pigmentosa* and *choroiditis disseminata* first manifest themselves, in the majority of cases, at the periphery of the fundus. Detachment of the retina, hemorrhages or serous exudations, and foreign bodies which have penetrated into the interior of the eye, are more frequently seen at the periphery than at the centre of the fundus.

Only, we must always remember the portion of the retina or of the globe of the eye which corresponds to the part examined. This is not always an easy matter when we come close to the periphery. There is no longer a point from which to mark our position. The vessels are distributed in a rather irregular manner, and there are only two things which can serve to guide us: 1st, the direction in which we look into the eye; 2d, the estimation of the distance which separates the point examined from the papilla.

We can easily know the direction in which we look into an eye if we use a simple ophthalmoscope, but if we employ an ophthalmoscope set in a tube we cannot tell in what direction the observed eye is looking.

To estimate the distance between the point under examination and the disk we take the latter as a point of departure, and say,

for example, a retinal hemorrhage is seen at two disk diameters from the inner edge of the disk, etc.

By neglecting to estimate this distance we are liable to fall into serious errors in regard to the real position of the point examined, which may lead to disastrous consequences. Such is the case where we have to search for a foreign body which has penetrated the eye, or when we have to determine if a certain part of the retina has given rise to a scotoma whose existence has been demonstrated on the perimeter.

LECTURE XXIII.

DIFFERENT FORMS OF THE OPHTHALMOSCOPE.

Gentlemen:—We have seen that the essential part of the ophthalmoscope is the mirror, either semi-transparent, or with a central perforation; that examination by the erect method requires a certain number of correcting lenses in order to adapt our eye to the eye under examination, and that in order to produce the inverted image we must, in the majority of cases, use a strong convex lens. A complete ophthalmoscope, therefore, is composed of a *mirror, correcting lenses, and one or more strong convex lenses.* We shall now examine the different forms which have been given to these three parts of the instrument, and the various methods of combining them.

All forms of mirrors have been used in ophthalmoscopy, the plane mirror, the concave, the convex, the prismatic, and mirrors made by silvering one surface of a lens or meniscus. Plane mirrors have been used which reflect a part of the light and allow another part to pass through, as, for example, those made of plates of plane glass superposed, or of *gilded* glass, which reflect more or less of the light, when inclined to a certain degree, and yet remain transparent. For this purpose, as well as for convex and concave mirrors, silvered glass, with the silvering rubbed off in the centre, or perforated, have also been used; finally, they may be made of polished metal with a central perforation. All these various forms can be used with advantage.

Helmholtz, in his ophthalmoscope, has used as a mirror a number of plates of plane glass superposed. By inclining them at a certain angle toward the source of illumination, he obtains a

polarized light and diminishes very considerably the reflections produced by the cornea and lens of the examined eye. This first ophthalmoscope has been furnished with five correcting lenses, which, being mounted on a disk eccentric in relation to the axis of the instrument, can be brought successively behind the mirror and in front of the eye of the observer.

It is a disk similar to this (which is called, after the name of the inventor, the *disk of Rekoss*) which we use at present to hold the correcting lenses.

The superposed plates of glass are not now generally used as a reflector, because it has been found that, with a little practice, it is easy to get rid of embarrassing reflections from the observed eye. But the *plane mirror* still remains the best we can use for many examinations. A plane mirror of silvered glass, or of metal, is to be preferred to the glass plates, because it is not so heavy and gives somewhat more light. The illumination which is obtained by means of an oil lamp and a plane mirror is much softer than the reflection from a concave mirror. The plane mirror is therefore used whenever the examined eye is very sensitive to light, and particularly for the examination of the erect image. A great advantage is thus gained by avoiding the contraction of the pupil, and the consequent narrowing of the ophthalmoscopic field. A plane mirror is, therefore, indispensable to a complete ophthalmoscope.

The perforation in the mirror should not be too small, as otherwise it will act as a stenopaïc hole, and in this way hinder the exact determination of the refraction. Neither should it be too large, because it will then intercept too great a portion of the light, and thus diminish the illumination. It should be, at least, three millimeters in diameter, and may be, without inconvenience, four.

Convex mirrors are never used alone in the construction of an ophthalmoscope. They are sometimes combined, as is also the plane mirror, with a convex lens, which concentrates the light on the mirror and in this way increases the illumination.

The only ophthalmoscope using the convex mirror is that of Zehender. This consists of a convex mirror of 16 centimeters radius of curvature, with a funnel-shaped perforation at its centre. At the sides of the mirror are two flexible arms, one of which holds the correcting glass while the other carries a convex lens of 13 dioptries, having about the same diameter as the mirror.

The observer gives to this lens such an inclination that it concentrates the light from the lamp at the side of the patient on the mirror. The arm holding this lens is adjusted to the side of the mirror next to the light, to the right or left, as the case may be.

Coccius and Follin have each combined, in a similar manner, a convex lens with a plane mirror.

This method of illumination is not very common, since we have a much better means of increasing the illumination in cases where the plane mirror does not suffice, by the use of the *concave mirror.*

The concave mirror gives a greater illumination than the plane mirror, because it concentrates the light, and is for this reason most generally employed.

The preferable focal distance is about twenty centimeters, and the diameter of the mirror should be from 25 to 30 millimeters. It is of no advantage to have it larger. It is not a matter of consequence whether it be made of glass or polished metal. If glass is used we strongly recommend that it be perforated, and that the edges of the perforation be blackened; simple removal of the silvering at the centre is not so good, the reflection from the posterior surface of the glass being a decided disadvantage.

It is of great advantage to have the mirror mounted on a *long handle.* The manipulation of the instrument is thus rendered much easier than when the handle is short.

In regard to the *correcting lenses,* as we have said, the disk of Rekoss, employed by Helmholtz, has remained the most convenient form which we can use. The advantage of this is that it enables us to rapidly change the correcting glasses. One inconvenience,

however, attending it, is that it is generally applied parallel to the mirror, and therefore the glasses have the oblique direction which we have to give the mirror when we reflect the light into the eye, and in thus looking obliquely through it it acts, in a sense, as a cylindrical lens. This is an objection which is often made against this disk, but I have found that the error which results from this position of the lens is so small as to be very properly neglected. It is only necessary to place the lamp, not so much to the side of the patient as a little behind him, in such a manner as will not require any great inclination of the mirror.

The great disadvantage of the disk of Rekoss and of those made since his is that they do not contain a sufficient number of lenses. Although with six different numbers and the assistance of the accommodation we can, in the majority of cases, see distinctly in the erect method, we are, nevertheless, debarred from one of the greatest advantages of ophthalmoscopy, the determination of the refraction.

It is for this reason that the diameter of Rekoss' disk has been very much increased and the diameter of the lenses diminished, so that there have been 25 lenses put in a disk of 31 millimeters diameter. The inconveniences of this large disk are that it makes the instrument very heavy, and the small lenses are difficult to clean, and besides, 12 concave and 12 convex lenses are not enough.

In order to overcome these inconveniences Loring had added to his ophthalmoscope three disks which can be introduced successively, and his instrument remained for a long time one of the most nearly perfect ophthalmoscopes we had. However, the replacing of the disks was inconvenient; it necessitated a loss of time; and since the introduction of the metrical system has rendered the combination of lenses much easier, we have had recourse, for the purpose of increasing the number of correcting lenses, to a very simple means. We combine the lenses by superposing them. We superpose two disks, each of which contains a

certain number of lenses. These two disks move independently of each other, and we can thus combine all the lenses of one disk with each lens of the other separately.

In this manner we obtain in a limited space a very long series of numbers.

There should be at least two *convex lenses* which are to be used in the production of the inverted image, one, No. 15 D, for the lower magnifying power, the other, No. 10 D, for the higher.

The concave mirror was introduced into practice by Jäger, of Vienna. The ophthalmoscope of Jäger consists of a very short cylindrical tube, cut obliquely at one of its extremities, at about an angle of 60°. This end is directed toward the eye to be examined, and has a plane or concave mirror, while the opposite end, or that turned toward the observer, receives the correcting glasses. The advantage of this form of ophthalmoscope is that it allows us to incline the mirror independently of the correcting glasses, so that the observer always looks through the lenses in the direction of their axes, and thus avoids the apparent astigmatism which results from their inclination. This influence of the inclination of the glasses is, however, not very great, if the precautions we have indicated be taken.

On the other hand, the ophthalmoscope of Jäger does not allow us to approach as near to the eye to be examined as the ordinary ophthalmoscopes do.

Latterly, a student of Jäger, Professor Schnabel, of Innspruck, has combined with Jäger's ophthalmoscope a number of disks containing correcting lenses which can be successively introduced into the instrument, as in Loring's ophthalmoscope. He has, moreover, added to the instrument the first mirror of Helmholtz, consisting of two thin plates of glass.

Liebreich, whose instrument with the concave mirror is most extensively employed, has attempted to render it available for demonstration. To this end he has taken away the handle of the mirror, and has placed the mirror and the convex lens used in

the inverted image in a tube blackened in its interior. The whole is fixed on a stand which makes it permanent when it is once adapted. It has also a chin-rest, on which the head of the examinee is supported, and a flexible arm, which carries a small ball of ivory, serving as an object of fixation for the eye under examination.

Galezowski has endeavored to utilize this instrument in practice by doing away with the accessory apparatus, retaining only the tube which is held in the hand. The usefulness of these ophthalmoscopes for demonstration is very problematical, and their application to practice is not to be recommended, because they deprive us of the great advantages of the examination by the upright image (greater enlargement and determination of the refraction); and furthermore, we never know in what direction the examined eye is looking.

It would be idle to enumerate the names of all those who have used the concave mirror for the construction of various kinds of ophthalmoscopes. Since its introduction into practice the concave mirror has undergone a number of minor alterations in form. It has been diminished in size and increased beyond measure; the handle has been discarded or replaced by the cover of the case which encloses both the mirror and the correcting lenses (Monoyer), or by a very small handle, etc.

I show you here an ophthalmoscope which I have myself constructed, and which unites all the conditions which I have mentioned, as being the best for practical purposes.

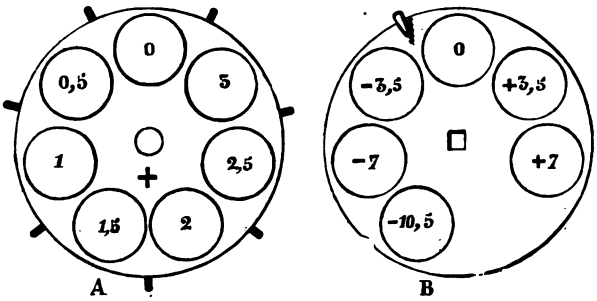
The mirror is concave; it has a focal distance of 20 centimeters and a diameter of 28 millimeters. It has a central perforation of at least three millimeters diameter; its handle has a length of about 12 centimeters, making the manipulation of the instrument very easy.

For the determination of the refraction this ophthalmoscope has two disks of the size indicated in Fig. 41, A and B. They are superposed on the instrument behind the mirror and revolve about the same centre.

The disk A contains six convex metrical lenses (Nos. + 0.5, 1, 1.5, 2, 2.5, 3) and a free opening, o.

The disk B contains two convex lenses (+ 3.5 and + 7), three concave (— 3.5, — 7, — 10.5) and a free opening, o.

FIG. 41.



In making the disks turn about their centres we can put all the lenses of each disk, as well as all possible combinations of the two behind the opening in the ophthalmoscopic mirror.

By placing behind the opening in the mirror the free opening of the disk B, and turning the disk A, we have passing in succession behind the opening the following numbers of convex lenses :—

0.
+ 0.5
+ 1.
+ 1.5
+ 2.
+ 2.5
+ 3.

If we now bring No. + 3.5 of the disk B behind the opening in the mirror and again turn the disk A, we obtain the following combination :—

$$0 + 3.5 = 3.5$$
$$0.5 + 3.5 = 4$$
$$1. + 3.5 = 4.5$$
$$1.5 + 3.5 = 5.$$

$$
\begin{aligned}
2 \quad &+ 3.5 = 5.5 \\
2.5 &+ 3.5 = 6. \\
3. \quad &+ 3.5 = 6.5.
\end{aligned}
$$

By placing No. + 7 of B behind the opening and again turning A, we produce—

$$
\begin{aligned}
0. \quad &+ 7 = 7 \\
0.5 &+ 7 = 7.5 \\
1 \quad &+ 7 = 8 \\
1.5 &+ 7 = 8.5 \\
2 \quad &+ 7 = 9. \\
2.5 &+ 7 = 9.5 \\
3 \quad &+ 7 = 10.
\end{aligned}
$$

We have now obtained, not counting zero, a series of 20 numbers of convexes (from 0.5 to 10 D) which corresponds to a series from No. 80 to No. 4 in the old system, all separated by an interval of one-half dioptry ($\frac{1}{80}$ old system).

To obtain the concave lenses we place the lens — 3.5 of the disk B behind the opening, and turning the disk A we obtain—

$$
\begin{aligned}
3 \quad &- 3.5 = - 0.5 \\
2.5 &- 3.5 = - 1. \\
2. \quad &- 3.5 = - 1.5 \\
1.5 &- 3.5 = - 2 \\
1. \quad &- 3.5 = - 2.5 \\
0.5 &- 3.5 = - 3. \\
0 \quad &- 3.5 = - 3.5.
\end{aligned}
$$

A combination of the lenses of the disk A with the No. — 7 of B gives—

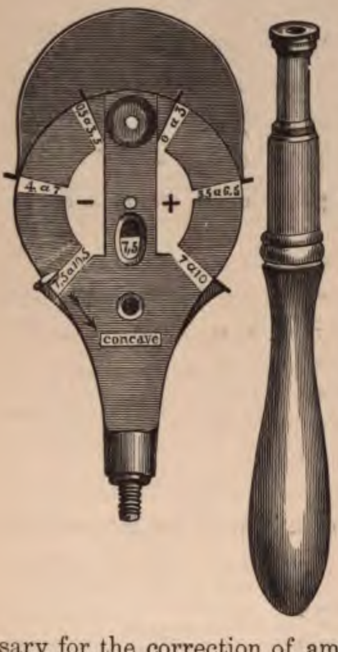
$$
\begin{aligned}
3 \quad &- 7 = - 4 \\
2.5 &- 7 = - 4.5 \\
2 \quad &- 7 = - 5 \\
1.5 &- 7 = - 5.5 \\
1. \quad &- 7 = - 6. \\
0.5 &- 7 = - 6.5 \\
0. \quad &- 7 = - 7.
\end{aligned}
$$

Finally, No. —10.5 of disk B combined with the lenses of disk A, gives the following numbers:—

$$3 - 10.5 = -7.5$$
$$2.5 - 10.5 = -8$$
$$2 - 10.5 = -8.5$$
$$1.5 - 10.5 = -9$$
$$1 - 10.5 = -9.5$$
$$0.5 - 10.5 = -10$$
$$0 - 10.5 = -10.5$$

We thus obtain a second series of 21 concave numbers from 0.5 to 10.5 (No. 80 to No. $3\frac{3}{4}$ of the old system) also separated by a common interval of 0.5 D.

FIG. 42.



Our ophthalmoscope, therefore, furnishes us with 42 different numbers of dioptries, without having to shift the disks, and has larger lenses and a smaller disk than any other refraction ophthalmoscope. Our lenses have a diameter of 1 centimeter, which allows of their being cleaned easily, and possesses the great advantage, also, that it allows them to be used for the subjective determination of the refraction and acuteness of vision. We have only to remove the mirror, and the instrument becomes an optometer, with which we can find the number of glass necessary for the correction of ametropia, as well as with the lenses in our trial cases.

A suitable mechanism discloses the number which results from any combination, so that there is never any need to make a calculation. (Fig. 42.)

This is a great advantage which my ophthalmoscope has over the others which have been constructed on the same principle. In these it is always necessary to add or subtract the two numbers of the combination, which causes loss of time, and is a frequent source of error.

The correcting lenses are plano-spherical, with their plane surfaces applied to each other.

The numbers from 0 to 10 dioptries, convexes, and from 0 to 10.5 concave, are sufficient for the determination of the refraction by means of the ophthalmoscope. We have need, sometimes, however, for stronger lenses in the determination of the acuteness of vision. We have, for this reason, added a concave No. 10 mounted on disk the same size as the mirror. This disk can be introduced in the place of the mirror, in the subjective examination of the acuteness of vision.

By turning the disks we are able to increase, at will, the power of this lens, and the result is always easy to calculate, since we have only to add the number read off on the ophthalmoscope to 10. We can in this way continue the series up to No. 20.5 (1.9 O. S.).

It is the same for the convex lenses: the positive lenses which we use in the production of the inverted image can be used in determining the acuteness of vision, and in the subjective determination of the refraction. We have only to introduce them separately in the place of the mirror. Thus No. + 10 added to the numbers contained in the instrument completes the series of numbers from convex 10 to 20 D. We thus double the number of our lenses, and while my ophthalmoscope gives 42 numbers for the ophthalmoscopic determination of refraction, it gives 84 for the subjective optometric determination.

The instrument can also be used for the determination of astigmatism by means of a stenopaïc slit in a disk of the same size as the mirror. This is introduced in the place of the mirror. We can give it any desired inclination, and the degree of inclination to the vertical is read off on the surface of the disk.

Recently I have modified the mechanism by leaving off one of the points of the disk A, and adding small buttons to the disk B.

When the disk A has made one turn, the finger which moves it no longer finds the stem, and it is thus warned to take one of the buttons of the disk B to continue the rotation. When one rotation of the disk A is made, it should stop until the disk B is moved up one glass, else we will go back to the number we began with.

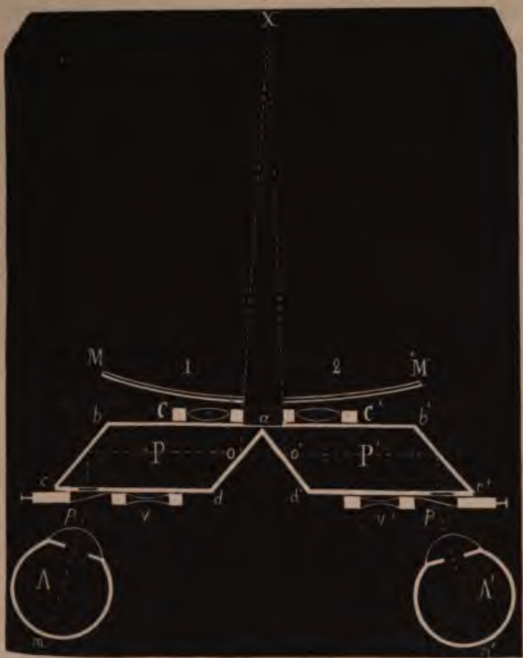
It is thus possible to make all the series of convex lenses from 0 to 10 D pass in front of the perforation in the mirror without removing the ophthalmoscope from the eye. On the other hand, by placing back of the opening in the mirror one of the concave lenses of the disk B we obtain, by pushing the points from below upward, the whole series of concave glasses without having to trouble with the hook of the disk B.

The principle of combining lenses in order to increase the number of glasses, has been used by a number of oculists, among others by Knapp, Loring, Wecker and Purves, but it is only since the introduction of the system of dioptrics that it has become really practicable.*

* Dr. E. G. Loring, of New York, has devised a metrical ophthalmoscope which differs from that of Dr. Landolt in many important particulars. It consists of a single disk and a segment of another disk. The single disk contains 16 glasses, from 1 to 7 D plus, and from 1 to 8 minus, with an interval of 1 D, which Dr. Loring considers sufficient for all ordinary purposes. If, however, higher numbers are desired, or smaller intervals (0.5 D), these are obtained by means of the quadrant, which contains four glasses, + 16 D, — 16 D, and + 0.5 D, and — 0.5 D, which can be brought round and applied over the glass of the disk behind the hole in the mirror. Thus, with the superposition of a *single* glass (+ 16 or — 16), and with an uninterrupted rotation, a series is obtained of successive dioptries from 1 to 23 plus, and from 1 to 24 minus, and a half series with the addition of the 0.5 D from 0.5 to 8 plus, and from 0.5 to 9 minus, or 65 glasses in all. The value of the glasses and the combinations is read off on the disk by a method peculiar to the instrument. This consists in having two concentric rows of figures, the outer of which shows the *real* value of the glass, and the *inner* the result of the combination when the supplementary glass is over the hole of the mirror. As the plus glasses are in *white* and the minus in *red*, and as the outer row is shut off when the inner is opened, no possible confusion can occur. Should the combination not be wanted, a trifling displacement of the quadrant to either side of the

There are two ophthalmoscopes having peculiar interest, one because it enables us to look at the fundus with both our eyes, the

Fig. 43.



binocular ophthalmoscope of Giraud-Teulon, the other because it

mirror hole at once dissolves it, and the instrument becomes a simple single disk ophthalmoscope.

The mirror of the instrument is Dr. Loring's "tilting" mirror, which is a modification of the old mirror obtained by cutting off the sides of the ordinary concave mirror, producing thereby a parallelogram 18 mm. in diameter, and 34 in length. The idea was suggested by Dr. Wadsworth's small circular mirror. Unlike this, however, it is designed for both the upright and inverted image, thus obviating a change of mirrors, it being found that abundant light is obtained for both methods. The mirror is swung on pivots which allows a tilting to either side of about 25 degrees. By this means the inclination of the correcting lenses is avoided, by which a large quantity of light is saved, and the image rendered free from distortion. The author considers this an indispensable adjunct to the instrument for those who desire to make accurate and easy examination by the upright method. For a fuller description, see the *Transactions of the American Ophthalmological Society*, 1878.—Tr.

enables two or more observers to look at the fundus at the same time, the demonstration ophthalmoscope of Sichel.

The ophthalmoscope of Giraud-Teulon is based on the same principle as the binocular microscope of Nachet. Its purpose is to obtain for each eye a different image of the fundus of the eye observed, so as to produce a stereoscopic effect.

A glass concave mirror M M (Fig. 43), of about 45 millimeters diameter, serves as a reflector. The silvering is removed at the centre, over an extent of 5.5 millimeters diameter. At the centre of this opening two glass prisms, a b c d and a′ b′ c′ d′ touch each other. The angles b a d and b′ a′ d′, and also the angles b c d and b′ c′ d′ are about 45°, so that the rays which fall as normals or under very small angles on b b′ undergo in each prism two total reflections, from a d toward b c, and from b c toward A, out of the prism into the eye of the observer. The same occurs on the other side.

Let x be an object and A A′ the eyes of the observer; each eye receives an image of part of x, as shown in Fig. 43, and these two images will show a greater difference, the larger the angle oxo′ is, that is, the closer the object is approached to the mirror, and the larger the central opening.

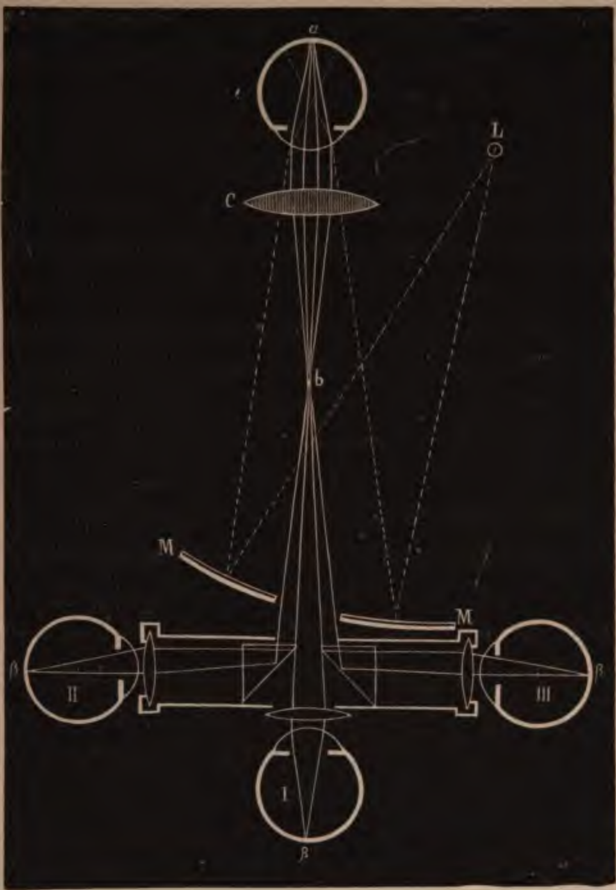
In order to adapt the instrument to the distance between the eyes of each observer, one of the prisms is divided, and its outer half can be approximated to, or removed from, the other, according to the distance which separates the two eyes. For the purpose of regulating the adaptation and the convergence, two small prisms (p p) are placed behind the openings in the ocular.

By placing behind the opening in the mirror one of the convex lenses enclosed in the groove C C, and in front of the oculars, the concave lenses *r* and *r′*, we add to the ophthalmoscope a kind of Gallilean telescope, and increase the magnifying power considerably.

This instrument has the advantage of showing the fundus of the eye in relief, and thus allows us to appreciate exactly any differences in the level of the background.

The ophthalmoscope of Sichel (Fig. 44) is designed to show to a number of observers at once the image of the fundus. It is composed of a concave mirror M M, of 35 centimeters focal distance, to which is adapted a metallic case on which it can be

FIG. 44.



moved in different directions. This case has a perforation of about 1 centimeter diameter through *both* walls in its centre, in the same axis with the perforation in the mirror. The form of the opening in the mirror is oval in its transverse axis. In the interior of the

case there is a rectangular prism whose hypothenuse is placed at an angle of about 45° to the axis of the case.

The plane corresponding to one of the sides of the right angle of the prism is brought up so as to occupy two-thirds of the opening in the mirror, leaving the other third free. One end of the case is closed, the other open. The latter is provided with an ocular in which correcting glasses can be placed. A convex lens, C, placed in front of the eye under observation forms an inverted image of the fundus at *b*.

A part of the light coming from this aerial image passes through the free portion of the opening of the mirror, and enters the eye of observer I directly. The other part meeting with the side of the prism is deflected from its course by the surface of the hypothenuse toward the eye of the second observer II.

The author, in his description of the instrument, which we borrow from the *Annales d'Oculistique* (T. lxvii), says that by adding a second case to the first, at some millimeters distance from it on the opposite side, it is possible to make the instrument available for three observers. The principal observer looking through the central perforation, or the space between the two cases, while each of the other observers looks through an ocular at the end of the cases.

Monoyer* has also carried out this principle, and showed us, in 1873, the first example of an ophthalmoscope for three observers.

* *Revue Medicale de Nancy.* Feb., 1874.

LECTURE XXIV.

SOURCE OF ILLUMINATION. EXAMINATION BY THE OBLIQUE LIGHT.

GENTLEMEN:—We have a word more to say in regard to the *source of illumination* for ophthalmoscopy. It is evident that the ideal illumination is that of the sun. It is not only the most intense—which, however, is not always an advantage in ophthalmoscopy—but the light is white, and shows us objects in their true color.

We always employ daylight, wherever it is possible, but most frequently we are compelled to have recourse to artificial light. In order to have daylight at our disposal we make an opening in the shutter. The room must be dark and the light entering through the opening must be the only light in the room. To make an ophthalmoscopic examination the patient is placed with his back toward the window, to the right or left of the opening. This light, though not so strong as that of a large lamp, is yet sufficiently strong for the examination of the fundus, and possesses notable advantages over the artificial light, among them the important one which we have mentioned, that we are enabled to better distinguish the shades of coloration of the fundus, which renders the diagnosis much more precise than when the examination is made by artificial light, which is always red. I cannot too strongly recommend to you the employment of daylight in ophthalmoscopic examinations.

It is hardly necessary to say that daylight has the same advantages in examinations by the oblique light, as with the ophthalmoscope.

*

We can use, as artificial light, indifferently, gas, oil or petroleum. When gas is used it is not generally best to turn it on to a full blaze, because then the illumination becomes too intense. The flame of an oil lamp is usually the most convenient source of illumination. You must not forget, as I have said, that artificial light gives an orange or reddish tint to all objects illuminated by it, which they have not by daylight. It should not be astonishing, therefore, to find the fundus of a different color, and paler, by sunlight, than by artificial light.

In making an ophthalmoscopic examination we place the lamp to the side of and behind the patient. The less the angle formed by the source of illumination and the mirror, the less must be the inclination of the mirror. This is a great advantage, because the illumination is then stronger, and the opening in the mirror through which we look is narrowed less, and the visual line is then found nearer the axis of the correcting lens.

It is indifferent whether we place the light to the right or the left of the patient. The mirror must be held lightly and by the end of the handle, by the three first fingers of the hand, in order to manipulate it as easily as possible.

We begin always by the examination of the upright image. After having thrown the light into the eye, we bring the ophthalmoscope as close to it as possible without obstructing the light by the head of the patient.

We keep the light in the proper direction by observing the pupil, which should appear brightly illuminated.

We then see the reflection of the mirror on the cornea, and on the anterior and posterior surfaces of the lens. These reflections, especially the first two, are frequently very annoying, so much so as to hide the objects which they overlie from our view.

It was for the purpose of doing away with this inconvenience that Helmholtz employed polarized light; by giving to his mirror an inclination of 56 degrees such light is not thrown back from the refracting surfaces of the eye.

In order to avoid the inconveniences resulting from these reflections we simply incline the mirror in such a manner that the reflections shall fall to the side of the parts to be examined.

The field of ophthalmoscopic observation is limited by the edge of the pupil. It follows that this is greater the closer we bring our eye to the observed eye, because the closer we approach to it the more we increase the angle of vision, the apex of which is in our eye, and whose sides touch the papillary borders.

It is an indispensable condition for a clear and distinct erect image of the fundus, as we have already said, that the eye of the examiner be accurately adapted to the eye under examination.

If we are dealing with emmetropic or hypermetropic eyes, our eye must be adapted for parallel or diverging rays. In such cases you must be on your guard not to make too great an effort of accommodation. This is a very important point, because at the beginning of your ophthalmoscopic practice you will experience a tendency to put forth more accommodative power in proportion as you see more indistinctly. This is due to the fact that account is not taken of the direction in which the rays come from the eye under examination. You feel instinctively that as the object is situated quite close to your eye you must, in order to see it distinctly, bring a strong accommodative power into play. You forget that the object to be observed is situated behind a lens formed by the dioptric media of the eye under examination, and that, consequently, the rays coming from it are much less divergent than if looked at with the naked eye.

If the object is situated at the focus of the lens, as in emmetropia, the rays, in passing out, are parallel, and we must completely relax our accommodation; if it is situated within the focus, as in hypermetropia, they pass out in a divergent manner, as if they came from an object situated at a certain distance behind the eye under examination, and we do not have need of any very considerable effort of accommodation.

Finally, in the case of myopia, we are in need even of a concave lens in order to see distinctly.

We have not, however, always command over our accommodation, since the ciliary muscle is not a muscle of the striated variety. But you will remember that the accommodation is in intimate relation with the convergence, and one is nearly always proportional to the other. Consequently, if we bring our eyes into a state of parallelism the convergence and accommodation are both abolished at the same time. Now, the muscles which preside over the direction of the eyes are under the control of the will, and we can easily gain a complete mastery over their movements.

To practice bringing the eyes into a state of parallelism we use a prism with its base turned toward the temple. The prism thus produces an apparent displacement of objects toward the temporal side, and in order to obtain simple binocular vision the eye covered with the prism must be turned outward. By using, therefore, stronger and stronger prisms we finally come to a parallel state of the visual lines. It is necessary that both eyes fix the same object, and as long as the object is seen single with the two eyes they are properly directed. In case the prism is too strong, that is, when the eyes are no longer able to produce the divergence which vision through the prism requires, we will see double, because one of the eyes is no longer directed to the object, and consequently its image is no longer formed on the macula. When you have once experienced the sensation characteristic of a parallel position of the eyes you will soon be able to bring it about spontaneously, and thereby relax your accommodation at will.

After having determined the refraction, we proceed with the examination by means of the inverted image, following the rules we have given above.

The convex lens should be held sufficiently far from the examined eye for its focus to fall near the plane of the pupil. By this means the diameter of the pupil is magnified as much as possible, and its borders disappear completely from the ophthalmoscopic field.

There is one inconvenience attending the inverted image which is not present in the examination by the erect method, and that is the double reflection of the light by the convex lens. To remove this we have only to slightly incline the lens, and the two reflections will disappear in opposite directions, and leave the centre free.

Beside the convex lens No. 10 or 15, by means of which the inverted image is produced, I always look through convex No. 3 in order to adapt my emmetropic eye to the distance of the inverted image. In this way I accustom my eye to always relax its accommodation when making an ophthalmoscopic examination.

The inverted image, as I have already told you, gives us a general view of the interior of the eye. We should examine the fundus in all directions up to its extremest limits, for reasons we have already indicated.

When we have found by the inverted image a diseased part, a pathological production, or any alteration whatever in the background of the eye, it is well to again have recourse to the erect image to appreciate more exactly the nature of the actual or suspected alteration.

EXAMINATION BY MEANS OF THE OBLIQUE ILLUMINATION.

The inspection of the anterior parts of the eye, by concentrating on them, by means of a lens, the light from a lamp or other source of illumination, is called the examination by the oblique light. We are, by this, able to examine, in turn, the following parts of the eye: the cornea, aqueous humor, iris, lens, and anterior portion of the vitreous humor.

In making this examination we use a lamp which can be advanced or withdrawn, raised or lowered, at will, in order to give the light all desired directions. The upper lid of the eye can be held gently by the thumb of one hand while the other hand holds a convex lens (about 15 or 20 D).

The light of the lamp concentrated by this lens is thrown on the different layers of the cornea, which we can examine very

minutely when the lamp is placed at the side of the patient so as to give to the light a direction tangent to the cornea. We can in this way not only make out trifling troubles in this tissue and mark their extent and thickness, but can also determine the exact depth of the tissue in which they are situated. We can thus estimate the depth of ulcers of the cornea, the form of their bases, the development of a hypopyon which, as we have demonstrated with Horner,* is never found in the thickness of the cornea, but commences by a deposit of pus on the posterior surface of the cornea, and increases and descends little by little into the bottom of the anterior chamber.

In the same manner we distinguish the punctiform opacities due to deposits of pus on the membrane of Descemet, so frequent in serous iritis.

We examine the aqueous humor in the same way.

By bringing the lamp a little further forward the iris is illuminated, and we can examine it throughout its whole extent by making the luminous cone traverse all its parts from the papillary border to the corneal margin.

In examining the crystalline lens we give to the light a direction a little less oblique, taking care to illuminate all its layers in succession.

The lens, even in a normal condition, and especially in old people, nearly always presents a diffuse, slightly grayish reflection, resembling mother of pearl. This must not be confounded with a commencing cataract, since, as we can convince ourselves by means of the ophthalmoscope, such lenses are perfectly transparent.

Cataract is characterized by alterations of a very marked nature. We must determine the part of the lens in which the opacities are situated, whether in the capsule or in the anterior cortical substance, in the nucleus, or in the posterior cortical substance. In order to arrive at a fine diagnosis, it is indispensable to vary

* Bokowa, Hypopyon-Keratitis. Thése de Zurich, 1871.

the direction of the light, by advancing or removing the lamp or the head of the patient, and placing it first on one side of him and then on the other.

When we wish to ascertain whether an opacity or foreign body is situated on the anterior or posterior surface of the lens, we can use, with advantage, the following method: Illuminate the eye with the mirror, as if for an ophthalmoscopic examination, holding it at a sufficient distance from the eye: the opacity will appear as a black spot on the illuminated field of the pupil. In causing the patient to look upward and downward the black spot will retain the same relative position to the papillary border, if the opacity is on the anterior part of the lens. It will, on the contrary, be displaced in a direction opposite to the movement of the eye, when it is found on the posterior part.

A posterior polar cataract will manifest itself by a reflection analogous to that of a concave mirror A simple senile cataract presents a greater or less number of black rays at the periphery of the lens. To examine the equator of the lens the pupil must be dilated with atropine.

After the lens, we examine the accessible portions of the vitreous humor. Floating bodies, crystals of cholesterine, parasites and foreign bodies having their seat in the anterior portion of the vitreous chamber are easily recognized by means of the oblique illumination. We can even sometimes detect a detachment of the retina and intraocular tumors.

As we have already said, by varying the position of the light we can give an astonishing precision to our diagnosis, and this precision is further increased when a second lens is used to magnify the parts illuminated by the first. This lens is held in the hand whose little finger supports the upper lid, elevating it a little.

The examination by means of the oblique light completes the list of methods for examining the eye, which it has been our purpose to set forth in these lectures.

NAME	DATE DUE